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Variations in caudal pigmentation in late-stage pre-extrusion larvae from *marinus*- and *mentella*-type female redfish from the Newfoundland area¹

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ABSTRACT

Late stage pre-extrusion larvae have been examined from 37 *marinus*-type and 44 *mentella*-type redfish, obtained from three localities in the Newfoundland area. Examination of 120 larvae from each fish has revealed that a difference exists between the two types, in the relative presence or absence of caudal melanophores in their larvae. The caudal melanophores, when present, are situated near the base of the caudal fin and ventral to the vertebral column. Caudal melanophores were absent in only 2.3% of the larvae from *mentella*-type parents in contrast to the absence of caudal melanophores in 76.1% of the larvae from *marinus*-type parents. When only those larvae having caudal melanophores are considered, larvae from *marinus*-type parents usually have but a single melanophore whereas those from *mentella*-type parents usually have two caudal melanophores.

This difference between larval samples provides evidence of the existence of a real genetic difference between *mentella* and *marinus* types of redfish in the Northwest Atlantic.

INTRODUCTION

TWO TYPES OF COMMERCIAL REDFISH are found in the North Atlantic. These are *Sebastes marinus marinus* (L.) and *Sebastes marinus mentella* Travin (Lundbeck, 1940; Kotthaus, 1950; Travin, 1951; Andriiashev, 1954; Kotthaus and Krefft, 1957; Baranenkova, 1957; Templeman, 1957; Templeman and Sandeman, 1957). The distribution of these two forms and some of the differences between them are described by Templeman (1959). While both are deep water forms, *Sebastes marinus mentella* (or, as we shall often refer to it, "the *mentella*-type redfish" or "*mentella*") occurs in deeper water than *Sebastes marinus marinus* ("the *marinus*-type redfish", or "*marinus*"). *Mentella*-type redfish are to be found in small numbers deeper than 400 fathoms (730 m) and they often have their centre of abundance between 200 and 300 fathoms (370–550 m), whereas the *marinus* type usually does not occur in abundance deeper than about 160–180 fathoms (290–330 m).

While in our opinion the larger *marinus*- and *mentella*-type redfish can usually be readily separated, so-called intermediate types exist, and there is some controversy regarding whether the differences between the two forms are adequate for the subspecific designations.

While the *marinus* type is very common in the Northeast Atlantic and at Iceland and Greenland, it is much less abundant over most of the area of the Northwest Atlantic from Labrador southward (Templeman, 1959).

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In Europe, but not in the Northwest Atlantic, the picture is further complicated by the presence of a small, shallow-water, essentially non-commercial species, *Sebastes viviparus* Krøyer (see Templeman, 1959, for the distribution of this species).

In an attempt to find a more secure basis for specific distinctions, we have carried out studies of the caudal melanophores in larvae from female parents of the *marinus* and the *mentella* types from the Newfoundland area. Areas, depths and dates of collection of these samples of larvae are given in Table I.

Tåning (1949) found large quantities of the fry of the common redfish *Sebastes marinus* (L.) in the area between the south of Iceland and Greenland and the area just north of Flemish Cap, a small bank to the east of the northern part of the Grand Bank. He states that in this area north of Flemish Cap he also found the young of the "American" redfish, which were considered to have been carried out from the Flemish Cap, or other parts of the Newfoundland banks area. In this area north of Flemish Cap the young of *Sebastes marinus* and of the American redfish could be obtained in the same haul.

Although Tåning evidently considered that he could readily distinguish the larva of the common European redfish from that of the typical American redfish, he makes no statement regarding the distinctions between them.

Subsequently in private conversations with Dr Tåning at various meetings of the International Commission for the Northwest Atlantic Fisheries (ICNAF), he described one of the main differences as being the possession of a large, more or less isolated ventral melanophore located in the caudal region of the larva of the American form (Fig. 1). This melanophore was absent in the larva of the European and Icelandic *Sebastes marinus*. In this respect, Tåning indicated that the larva of the American form was similar to that of *Sebastes viviparus* rather than to that of *Sebastes marinus*.

Dannevig (1919, plate I) shows 2 larvae of *Sebastes marinus* each with a single ventral caudal melanophore. One of these, an 8 mm larva obtained in a surface plankton tow in the Gulf of St. Lawrence, in mid-channel between Gaspé and Anticosti Island on June 26, 1915, shows the caudal melanophore in the typical expanded condition at an angle to the vertebral column. The other larva showing the caudal melanophore is a 10.4 mm larva obtained in a surface plankton tow in Cabot Strait on August 12, 1915. In the same plate Dannevig also features a 5.6 mm larva obtained from a parent redfish from Kristianiafjorden (Oslo Fjord) in July, 1913. This larva apparently possesses a ventral caudal melanophore. It is most likely, however, both from the place and month of capture, that this is a larva of *Sebastes viviparus* rather than of *Sebastes marinus mentella*.

The ventral caudal melanophore is to be seen in the diagrams of the redfish larva in the egg and the 6, 9 and 12 mm redfish larvae shown in Bigelow and Welsh (1925, fig. 143-146). These larvae of Bigelow and Welsh, however, do not show the typical angular orientation of these caudal melanophores to the vertebral column which can be seen in Fig. 1.

Williamson (1911, plate III, fig. 76 and 78) shows 2 late-stage, pre-extrusion larvae of *Sebastes marinus* taken in June from the ovary of the parent female,

TABLE I. Location and dates of collection of samples of late stage pre-extrusion larvae from female redfish parents, used in the present study. (Research vessel *Investigator II* and *Marinus* cruises, 100 fath = 183 m).

Locality	Position		Depth	Redfish female parent type	No. larval samples and parent females	Dates of collection 1958	Length of parent females	
	Lat. N	Long. W					Range	Average fork length
Hermitage Bay	47°33'	56°13'	fath 120-127	<i>marinus</i>	11	May 12-13	cm 37-51	cm 41.6
Connaigre Bay ^a	47°23'	56°12'	109-121	<i>marinus</i>	2	May 16-17	36-37	36.5
Hamilton Inlet Bank	54°38'	53°25'	250-256	<i>marinus</i>	24	June 10	40-52	45.1
Hermitage Bay	47°33'	56°05'	132-140	<i>mentella</i>	23	July 3-4	33-41	37.7
Hermitage Bay	47°33'	56°05'	132-140	<i>mentella</i>	7	July 8, 11	35-41	38.4
Flemish Cap	46°35' to 46°49'	46°46' to 45°32'	150-204	<i>mentella</i>	2	June 25, 27	37-38	37.5
Flemish Cap	47°27' to 47°30'	45°50' to 45°52'	148-170	<i>mentella</i>	10	June 29-30	35-39	36.7
Hamilton Inlet Bank	54°30' to 54°38'	53°25' to 53°38'	151-250	<i>mentella</i>	2	June 10	33-45	39.0

^aIn the text the Connaigre Bay samples have been considered to be from Hermitage Bay.

and with dorsal and ventral pigment well enough developed for the caudal melanophores to be present, but the larvae show no caudal melanophores. Williamson's mature females of "*Sebastes marinus*" taken in June, consisted of small 18–24 cm redfish from the North Sea, which were almost certainly *Sebastes viviparus*, and of large 38–42 cm mature females from an unknown locality. These may well have been *Sebastes marinus marinus*. Since Tåning, in private conversation, has indicated that the larvae of *Sebastes viviparus* possess a ventral caudal melanophore, Williamson's larvae were most likely not from *viviparus*.

Jensen (1922, fig. 1) shows an 8.7 mm larva of *Sebastes marinus* obtained south of Denmark Strait (58°08'N, 39°10'W), on the surface above a depth 1,600 fathoms (2,900 m) on May 26, 1908. The pigmentation is carefully drawn and described, but no ventral caudal melanophore is shown or mentioned. This is most likely a *marinus*-type larva.

Lüling (1951) described larvae of *Sebastes marinus* obtained from the ovaries of the parent females. He traces in detail the development of the pigment during the various phases of larval growth, but at no time does he mention a ventral caudal melanophore. At least 2 of the redfish larvae shown by Lüling (fig. 17a and 19a: 5 and 6 mm larvae from females 53 and 50 cm long, taken south of Iceland on May 4 and 5, 1948) are well enough developed for caudal melanophores to be present, but although the dorsal and ventral chromatophores are well featured there is no ventral caudal melanophore.

Goodchild (1925) has given a drawing of a 5.6 mm larva obtained from a female redfish from Lousy Bank (almost midway between Scotland and Iceland) at a depth of 200 fathoms (370 m) in April, 1921. Dorsal and ventral pigment was also featured and described, the latter "commencing slightly behind the anus and continuing to within a short distance of the end of the tail", but no indication was given that a separate ventral caudal melanophore was present.

MATERIAL AND METHODS

In April, May and June, 1958, whole ovaries containing late stage pre-extrusion larvae were obtained at sea from *marinus*- and *mentella*-type redfish. Females with late stage larvae usually had larvae running from the oviducts. To prevent contamination with larvae from other fish, each fish was carefully washed with sea water to remove all surface larvae. The measuring board, knife and other equipment, also, were washed before cutting out the ovary for preservation in 5% formalin.

Since in most areas the late stage pre-extrusion larvae were available from the *marinus*-type fish several weeks earlier than from the *mentella* and were usually obtained from separate cruises or at least from separate sets, there was little chance of contamination between samples of *marinus* and *mentella* larvae.

Larvae were also obtained from female redfish brought under ice to the St. John's Station, but often in these the caudal melanophores were partially disintegrated and thus were unsuitable for a careful study. For this reason only data from larvae freshly preserved at sea have been used in this paper. Only pre-extrusion larvae in a late stage of development were used in the study of the

ventral caudal melanophores. The stage of dorsal and ventral body pigmentation and the yolk-sac size were noted in *mentella* larvae with definite caudal melanophores in all or almost all larvae. All samples of earlier stage larvae than those possessing definite caudal melanophores, such as larvae with too little development of dorsal and ventral body pigmentation, and in fact all samples for which it was doubtful whether they had reached a late-enough stage of development for caudal melanophores to be present, were discarded. Most samples of larvae were approximately ready for extrusion. All the others except 1 (4+ weeks) were estimated, from the stage of development and from our knowledge of the spawning period, to be approximately within 1 to 3 weeks of extrusion (Table II). There is no evidence whatever (Table II) that, of the larval samples used, those furthest from extrusion possessed less larvae with caudal melanophores or less total caudal melanophores per sample than those approximately ready for extrusion. In a single redfish ovary the larvae are usually in approximately the same stage of development. On the average the *marinus*-type larvae were somewhat closer to extrusion than the *mentella*-type (Table II). Thus the possession of more caudal

TABLE II. Relationship of stage of development of redfish larval samples (of Table I) to numbers of larvae with caudal melanophores and to total numbers of caudal melanophores.

Estimated no. of weeks to extrusion	Yolk sac stage	Total larvae (out of 120) with 1 or more caudal melanophores		Total no. caudal melano- phores in 120 larvae		Total larval samples and redfish parents
		average (range)		average (range)		
FEMALE PARENTS OF THE <i>mentella</i> TYPE						
0 to 0+	Yolk sac very small and included in normal body shape	116 119	(58-120) (108-120) ^a	208 214	(63-268) (143-268) ^a	23 22 ^a
1 to 2	Yolk sac small, moderately rounded and protruding	113	(100-120)	197	(163-215)	3
2+ to 3+	Yolk sac large and well rounded	120	(116-120)	240	(214-286)	17
4+	Yolk sac large and well rounded	119	(119)	225	(225)	1
FEMALE PARENTS OF THE <i>marinus</i> TYPE						
0 to 0+	Yolk sac very small and included in normal body shape	29	(8-63)	32	(8-83)	24
1 to 2	Yolk sac small, moderately rounded and protuding	23	(3-58)	24	(3-60)	7
2+ to 3+	Yolk sac large and well rounded	32	(7-62)	35	(7-77)	6

^aOmitting the sample with 58 larvae with caudal melanophores and a total of 63 caudal melanophores.

melanophores by the *mentella* type could not have been due to a later stage of development of the *mentella* larvae. Once it had been decided that a sample was suitably well developed for detailed examination, no choice was made in the larvae examined beyond the tendency to pick the straighter, rather than the coiled, specimens. Only larvae already hatched were used. Caudal melanophores are present in the later-stage larvae within the eggs but larvae were not dissected from eggs for inclusion in these samples. At the Biological Station, the larvae were emptied from the preserving bottle into a dish, larvae picked out at random using the naked eye only, and about 20 at a time laid in a row on a glass slide where they were examined by the senior author under a binocular microscope. The number of ventral caudal melanophores was counted, usually with the left side of the larva upward. In addition to the count of melanophores, an appraisal of the state of expansion of the melanophores was also made, as this might affect the reliability of the counts. The three grades "expanded", "half expanded" and "contracted" were used.

The female parents of these larvae were all tagged, brought to the Biological Station, examined and checked (entirely without relation to larval appearance) for *marinus* and *mentella* type by both authors, and photographed. The larvae were examined several months later. There were usually large quantities of larvae in each bottle, the latter being kept in the dark. Under these conditions the pigmentation of the larvae was normally in excellent condition when examined.

POSITION AND GROSS STRUCTURE OF THE CAUDAL MELANOPHORES

The caudal melanophores, when present, are situated near the base of the caudal fin ventrally to the vertebral column (Fig. 1). When only one melanophore is present, it is usually placed midway between the two cell aggregations or neuromasts which are a conspicuous feature of the caudal region of the larvae. When more than one melanophore is present, the posterior one is normally midway between the neuromasts and the others are situated anterior to this, usually in a line sloping towards the anterior neuromast. This dorso-ventral and antero-posterior positioning of the caudal melanophores can clearly be seen in Fig. 2. Not so easily seen is the lateral positioning of the melanophores, and as this may affect the ease with which the melanophores may be observed, as well as the actual number counted, it is important that this be examined.

Serial sections were cut through the caudal region of several larvae. The larvae, which had been fixed in 5% formalin, were embedded in paraffin wax and sections cut at 15 μ . The sections were stained very lightly with eosin to allow the tissue to be easily visible. Some difficulty was found in preventing the delicate medial connective tissue of the caudal fin fold from tearing which allowed the two external portions to separate.

Fig. 3B and 3C show consecutive sections through two of the larvae. The sections shown in Fig. 3B illustrate the general positioning of the caudal melanophore in relation to the other tissues of the tail. Very little tearing of the medial connective tissue is apparent ventral to the vertebral column in these sections,

although a comparison of Fig. 3B(1) with Fig. 3B(3) does reveal that, in the latter, some separation of the ventral medial connective tissue appears to have taken place, and the caudal melanophore is torn apart.

In Fig. 3C considerable tearing of the medial connective tissue and separation of the external portions has taken place. The significant point in these sections is that the tearing has taken place on different sides of the melanophore in different sections. In sections (1), (2) and (3) the tearing has left the melanophore intact in the tissue to the right, whereas in section (4) the bulk of the melanophore is to be seen in the tissue to the left. Although a small amount of melanophore substance can be seen remaining on the right in section (4) it is evident that the melanophore is single.

Occasional larvae were found which, when they were examined from one side, showed one or two of the melanophores to be situated nearer the surface than the others. In these larvae, it was evident that the melanophores did not lie in the same lateral plane, but no successful sections were obtained through larvae with abnormally positioned melanophores of this type.

It is concluded from the sections, as well as from the examination of numerous larvae, that each caudal melanophore is normally single and positioned medially in the connective tissue ventral to the vertebral column, and is visible to the same extent when either side of the larva is examined.

DIFFERENCES BETWEEN *MARINUS*- AND *MENTELLA*-TYPE REDFISH IN NUMBER OF CAUDAL MELANOPHORES

In a total of 4,400 *marinus*-type larvae (120 from each of 37 *marinus* females) 3,378 or 76.1% possessed no caudal melanophores. Out of 5,280 *mentella*-type larvae (120 from each of 44 *mentella* females) only 124 or 2.3% possessed no caudal melanophores. All 37 *marinus* parent females had from 57 to 117 larvae (out of 120) without caudal melanophores. Of 44 *mentella* parent females (120 larvae each) 29 possessed no larvae without caudal melanophores, 7 had 1 larva without caudal melanophores, 4 had from 2 to 4 larvae without caudal melanophores and only 4 had more than 10 larvae without caudal melanophores. Of these latter 4 fish only 1 had more than 20 larvae without caudal melanophores, and this specimen, with 62 larvae without caudal melanophores was the only *mentella* parent female whose numbers of larvae without caudal melanophores overlapped those of the *marinus*-type females (Table IIIA).

Similarly in Table IIIB, which shows the total number of caudal melanophores in samples of 120 larvae per parent female, only the larvae of the same single *mentella* female, with 63 caudal melanophores in 120 larvae, overlaps the *marinus* range. Otherwise the ranges are quite distinct, with a total range per larval sample of 3-83 melanophores per larval sample in *marinus*, and 143-286 melanophores in *mentella*.

Similarly, when only these larvae which possess caudal melanophores are considered there are fewer of these melanophores in *marinus*-type larvae (which typically have only one caudal melanophore), than in *mentella*-type larva, which

TABLE III. Caudal melanophore frequency in samples of redfish larvae from *marinus*- and *mentella*-type female parents. (Hermitage Bay, Flemish Cap and Hamilton Inlet Bank, May-July 1958; *marinus* and *mentella* types. These are the same samples described in Table I.)

A			B			C		
No. of larvae (out of 120) with no caudal me- lanophores	No. of redfish		Total no. of caudal me- lanophores in 120 larvae	No. of redfish		Av. no. caudal me- lanophores per larvae with 1 or more me- lanophores (120 larvae)	No. of redfish	
	<i>marinus</i> -type female parent	<i>mentella</i> -type female parent		<i>marinus</i> -type female parent	<i>mentella</i> -type female parent		<i>marinus</i> -type female parent	<i>mentella</i> -type female parent
0	...	29	0	...	...	0.01-0.09	...	...
1	...	7	1-10	7	...	0.10-0.19	...	...
2	...	1	11-20	6	...	0.20-0.29	...	...
3	...	2	21-30	6	...	0.30-0.39	...	...
4	...	1	31-40	7	...	0.40-0.49	...	...
5	...	...	41-50	6	...	0.50-0.59	...	...
6-10	...	...	51-60	2	...	0.60-0.69	...	...
11-15	...	2	61-70	1	1	0.70-0.79	...	...
16-20	...	1	71-80	1	...	0.80-0.89	...	...
21-25	...	...	81-90	1	...	0.90-0.99	...	...
26-30	...	...	91-100	...	...	1.00-1.09	32	1
31-35	...	...	101-110	...	...	1.10-1.19	2	...
36-40	...	...	111-120	...	...	1.20-1.29	2	...
41-45	...	...	121-130	...	...	1.30-1.39	1	1
46-50	...	...	131-140	...	...	1.40-1.49	...	1
51-55	...	...	141-150	...	1	1.50-1.59	...	2
56-60	3	...	151-160	...	1	1.60-1.69	...	6
61-65	1	1	161-170	...	1	1.70-1.79	...	5
66-70	1	...	171-180	...	...	1.80-1.89	...	6
71-75	2	...	181-190	...	3	1.90-1.99	...	7
76-80	2	...	191-200	...	4	2.00-2.09	...	5
81-85	5	...	201-210	...	3	2.10-2.19	...	7
86-90	4	...	211-220	...	6	2.20-2.29	...	2
91-95	...	...	221-230	...	7	2.30-2.39	...	1
96-100	5	...	231-240	...	2	2.40-2.49	...	...
101-105	4	...	241-250	...	5	2.50-2.59	...	...
106-110	5	...	251-260	...	7	2.60-2.69	...	...
111-115	4	...	261-270	...	2			
117	1	...	271-280	...	...	
			281-290	...	1			
Total	37	44		37	44		37	44

usually have 2 to 4 melanophores. There is very little overlapping in range (Table IIIC), and there are, on the average, 1.07 caudal melanophores for *marinus*- and 1.88 for *mentella*-type larvae (Table IV). When larvae without caudal melanophores are included the averages become 0.26 for *marinus* and 1.83 for *mentella*. The percentages of larvae with 1 to 4 caudal melanophores in 1,062 *marinus*- and 5,156 *mentella*-type larvae possessing at least 1 caudal melanophore are:

Redfish type	1	2	3	4
<i>marinus</i>	93	7	0.3	0
<i>mentella</i>	28	57	13	1

Fig. 4 and 5 show 6 *mentella*- and 6 *marinus*-type larvae containing caudal melanophores. The larvae were randomly picked from those possessing caudal melanophores, the first larva found with a caudal melanophore being photographed. The parent fish were chosen, as far as possible, to show examples from the range when "total larvae with one or more caudal melanophores" is considered. Photographs of the parent female redfish are also shown, together with ventral views of the lower jaw, and these indicate clearly the differences in the sharpness of the chin beak in the round-chinned *marinus* and the sharp-chinned *mentella* types. These fish were collected at sea by technicians and examined at the Station by the authors. The numerous *marinus* characteristics, such as the rounder chin beak, smaller eyes, thicker skin, better retention of scales, and thicker spines than the *mentella* form, the yellowish or orange colour of *marinus* rather than the red of *mentella*, and the generally different body appearance, allowed the two forms to be readily distinguished and in no case was there a difference of opinion regarding whether a fish was of the *marinus* or of the *mentella* type.

It is evident, when the whole larvae are examined, that the larvae obtained from *marinus*- and *mentella*-type fish are very similar in shape and form. The difference between the melanophores is shown in the photographs of the enlarged caudal peduncle region of the larvae. In this connection, it should be noted that Fig. 4A shows the one *mentella* fish that overlaps in the tables with *marinus*-type fish.

The state of expansion of the caudal melanophores of each larva was recorded (Fig. 2, Table V). The counting of caudal melanophores could be done very accurately when the melanophores were contracted or in the early stages of expansion, but probably less accurately when the caudal melanophores were fully or almost fully expanded.

In Table VE, VJ and VK for *mentella*-type larvae, there is evidence that the average number of caudal melanophores recorded per larva is progressively less in passing from the contracted through the partly expanded to the fully expanded state. In the more expanded stages, the numbers of larvae recorded with more than 2 caudal melanophores are less, and the average number of melano-

TABLE IV. Total and average numbers of caudal melanophores in samples of redfish larvae from *marinus*- and *mentella*-type female parents. (Hermitage Bay, Flemish Cap and Hamilton Inlet Bank, May to July 1958. These are the same samples described in Table I.)

No. of larvae (out of 120 from one parent) possessing 1 or more caudal melanophores	No. of parent redfish		No. of larvae (possessing 1 to 4 caudal melanophores) from all female parents (120 larvae per parent female)								Total no. melanophores per 120 larvae per parent	Av. no. melanophores per larva with one or more melanophores		Av. no. melanophores per larva in 120 larvae per parent		
			<i>marinus</i>				<i>mentella</i>									
	<i>marinus</i>	<i>mentella</i>	1	2	3	4	1	2	3	4		<i>marinus</i>	<i>mentella</i>	<i>marinus</i>	<i>mentella</i>	<i>marinus</i>	mentella
0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1-5	1	...	3	...	...	...	...	...	...	...	3	...	1.00	0.03	...	...
6-10	6	...	52	...	...	...	...	...	...	...	52	1.00	0.07	...	...	...
11-15	5	...	69	1	...	...	...	...	...	...	71	1.01	0.12	...	...	...
16-20	2	...	30	6	...	...	...	...	...	...	42	1.17	0.18	...	...	...
21-25	5	...	111	4	...	...	...	...	...	...	119	1.03	0.20	...	...	...
26-30	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
31-35	5	...	153	7	1	...	...	...	...	...	170	1.06	0.28	...	...	...
36-40	4	...	143	6	...	...	...	...	...	...	155	1.04	0.32	...	...	...
41-45	3	...	126	7	...	...	...	...	...	...	140	1.05	0.39	...	...	...
46-50	1	...	47	...	...	...	...	...	...	...	47	1.00	0.39	...	...	...
51-55	1	...	51	1	...	...	...	...	...	...	53	1.02	0.44	...	...	...
56-60	1	1	56	2	...	...	53	5	...	...	60	1.03	0.50	0.53	...	...
61-65	3	...	147	37	2	...	...	...	...	...	227	1.22	0.63	...	...	...
66-70	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
71-75	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
76-80	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
81-85	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
86-90	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
91-95	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
96-100	...	...	...	...	...	...	40	57	3	...	...	...	...	...	...	...
101-105	1	...	...	...	...	...	...	...	...	...	163	...	1.63	...	1.36	...
106-110	...	2	...	...	...	...	139	73	5	...	300	...	1.38	...	1.25	...
111-115	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
116-120	...	40	...	...	...	...	1,229	2,803	682	67	...	9,149	...	1.91	...	1.91
Total	37	44	988	71	3	...	1,461	2,938	690	67	1,139	9,675	1.07	1.88	0.26	1.83

phores recorded declines from 2.08 in the fully contracted state to 1.90 in the partly expanded and to 1.77 in the fully expanded state. In the *marinus* type, most larvae have only one caudal melanophore.

When several fully contracted or partly expanded melanophores are present, it can sometimes be noted in observations from one side that some melanophores are superficial but others are deeper down. While, because of the thinness of the caudal fin fold, all the melanophores are distinct enough to be counted at once at the same focus, some can be rendered more distinct by focussing slightly lower. It is possible that in such cases, although there is a good chance that all contracted melanophores will be seen, in the fully expanded state some of the deeper melanophores may occasionally be covered and not be visible. In the partly expanded state this will sometimes be the case but less often than in the fully expanded. With the expanded melanophores, also, and especially in the fully or almost fully expanded state, the number of melanophores must often be estimated from the probable centres of the melanophores rather than counted with the absolute precision possible in the contracted state.

The slight variations in numbers of larval melanophores, due to conditions of expansion and difficulties in counting, are of no importance in the separation of the *marinus* and the *mentella* types of larval samples, because even the lowest averages for the numbers of fully expanded melanophores of *mentella*-type fish are well above those for the highest averages of all expansion or contraction stages for the *marinus* type. Since most of the *mentella* larvae had more than one caudal melanophore, and a smaller percentage of the caudal melanophores of *marinus* larvae than of the *mentella* were in a fully expanded state, the differences indicated in Tables III to V, between the numbers of caudal melanophores in the *mentella* and the *marinus* larvae, would be even greater if the caudal melanophores of the *mentella* larvae had been as fully contracted as those of the *marinus* larvae.

DIFFERENCES BETWEEN AREAS. Considering the slight errors in counting which may occur when the caudal melanophores are in an expanded state, and that a greater proportion of the Flemish Cap *mentella* larvae possesses expanded caudal melanophores, the slight difference in the number of larval melanophores for *mentella* larvae in Table VA between the Hermitage Bay and Flemish Cap areas is not significant. It is possible that the larvae of *mentella*-type redfish from east of Hamilton Inlet Bank in Labrador may have more caudal melanophores than those of Hermitage Bay and Flemish Cap, but the numbers of parent females (2) from this area are not enough to allow such a conclusion to be drawn.

The *marinus*-type larvae from both Hermitage Bay and Hamilton Inlet Bank have comparably few caudal melanophores. The latter area has both a slightly greater number of larvae with caudal melanophores — 31 against 24 (Table VD) and a slightly higher number of melanophores per larva — 0.28 against 0.21 (Table VB), than the former. These differences, however, are not significant. (For the difference in the number of larvae with caudal melanophores $t = 1.26$.)

The numbers of larvae with caudal melanophores and the numbers of caudal melanophores present per larva were very similar in *mentella* specimens from

TABLE V. Numbers of redfish larvae with 1 to 4 caudal melanophores in various states of expansion. (Larvae are from 44 *mentella*- and 37 *marinus*-type female parents, from each of which 120 late stage larvae were examined for caudal melanophores. These are the same larval samples described in Table I.)

Locality	No. of larvae (out of 120 per female parent redfish) with 1 to 4 caudal melanophores																Total melanophores	Av. no. melanophores per larva (120 larvae per parent)						
	Contracted				Half expanded				Expanded				Total						% of total					
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4			1	2	3	4		
	Total larvae																							
	A. FROM <i>mentella</i> FEMALE PARENTS																							
Hermitage Bay	30	146	419	181	20	482	946	237	29	342	634	58	...	970	1,999	476	49	3,494	28	57	14	1	6,592	1.83
Flemish Cap	12	26	17	17	1	115	197	55	8	323	568	88	7	464	782	160	16	1,422	33	55	11	1	2,572	1.79
Hamilton Inlet Bank	2	...	...	...	...	4	44	25	1	23	113	29	1	27	157	54	2	240	11	65	23	1	511	2.13
B. FROM <i>marinus</i> FEMALE PARENTS																								
Hermitage Bay	13	170	2	...	...	68	13	...	...	57	3	...	...	295	18	...	...	313	94	6	0	0	331	0.21
Hamilton Inlet Bank	24	44	1	...	...	443	38	3	...	206	14	...	...	693	53	3	...	749	93	7	0.4	0	808	0.28
Average no. of larvae (per female parent redfish) with 1-4 caudal melanophores																								
C. FROM <i>mentella</i> PARENTS																								
Hermitage Bay	30	4.9	14.0	6.0	0.7	16.1	31.5	7.9	1.0	11.4	21.1	1.9	0	32.3	66.6	15.9	1.6	116.5	...	...	...	...	...	...
Flemish Cap	12	2.2	1.4	1.4	0.1	9.6	16.4	4.6	0.7	26.9	47.3	7.3	0.6	38.7	65.2	13.3	1.3	118.5	...	...	...	...	...	...
Hamilton Inlet Bank	2	...	...	...	...	2.0	22.0	12.5	0.5	11.5	56.5	14.5	0.5	13.5	78.5	27.0	1.0	120.0	...	...	...	...	...	...
D. FROM <i>marinus</i> PARENTS																								
Hermitage Bay	13	13.1	0.2	...	...	5.2	1.0	...	...	4.4	0.2	...	...	22.7	1.4	...	...	24.1	...	...	...	...	...	...
Hamilton Inlet Bank	24	1.8	0.04	...	...	18.5	1.6	0.1	...	8.6	0.6	...	...	28.9	2.2	0.1	...	31.2	...	...	...	...	...	...

all 3 widely separated areas, and very similar in *marinus* specimens from 2 widely separated areas. In each individual area, the samples of *marinus*-type larvae were widely distinct from those of the *mentella* type.

DISCUSSION AND CONCLUSIONS

In the Newfoundland area it is evident that, but for the occasional error that could be made with samples from exceptional *mentella* female parents (and possibly also *marinus* parents although as yet we have no evidence for this), samples of late stage pre-extrusion larvae of *mentella* females are well separated from those of *marinus* females by the numbers of larvae without caudal melanophores, and by the total numbers of caudal melanophores in a sample of larvae. Populations of *marinus* and of *mentella* could readily be separated by this means with only occasional errors. In speaking of the *Sebastes marinus mentella* of the Northwest Atlantic, including the Newfoundland area, it must be remembered that at the present time no samples of late stage pre-extrusion larvae of either *marinus* or *mentella* females from the European area have been examined, or at least described; and the possibility exists that the *mentella* type of Europe may be different from the American *mentella* type, and may possess no caudal melanophores.

It is evident from Tåning's observations (1949 and private communications previously mentioned) of free *Sebastes* larvae in plankton samples, that caudal melanophores must be rare or absent in one or both of the main commercial types of European redfish, and we presume that it is the European *marinus* which is lacking caudal melanophores. However, a careful study of late stage pre-extrusion larvae from *marinus* and *mentella* females will be necessary to make certain whether Tåning's observation was particular and individual, applying to every European redfish larva, or a generalized one applying only to most European *marinus* larvae or to the *mentella* larvae also.

In this regard, while some *marinus* larvae have distinct though few caudal melanophores, we have sometimes noted *marinus* larvae with very faintly pigmented caudal melanophores which would be easy to miss either in the contracted or the expanded state.

Not only were the numbers of caudal melanophores greater in the *mentella* larvae, but the total amount of black pigment in the caudal melanophores (of larvae possessing caudal melanophores), was also noticeably greater on the average in *mentella* than in *marinus* larvae. This was true, on the average even when *mentella* and *marinus* larvae possessing only one caudal melanophore were compared.

The great numbers of redfish larvae, which were reported by Tåning (1949) as occurring over wide areas south of Iceland and Greenland almost to Flemish Cap, apparently usually possessed no caudal melanophores. Thus, unless European *mentella*-type redfish also have no caudal melanophores, these were actually *marinus*-type larvae. If this is the case, it follows that, if large pelagic populations exist over this deep oceanic area they are likely to be of *marinus* and not of *mentella*. This observation, if correct, and the relative lack of *marinus* in the

southern part of the western North Atlantic redfish area, will reinforce our arguments (Templeman, 1959) that large pelagic populations of redfish are unlikely to exist seaward of the continental slope in the southern parts of this area.

Considering the very wide area examined from Labrador to Flemish Cap to Hermitage Bay, it is a surprising commentary on the genetic stability of each of the *marinus* and *mentella* types over this great area that, although the *marinus* and *mentella* larval samples themselves are extremely well differentiated, no significant differences within the same types were found between areas. (Doubtless, however, if many larvae of large enough samples of females of either type are examined, some small significant between-area differences will be demonstrated.)

Even with the information we have at present for the Northwest Atlantic, where no complication from the presence of *Sebastes viviparus* larvae exists, it is evident that the examination of fresh collections of recently extruded larvae, collected throughout the spawning seasons of both forms, may give some indication of the numbers of *marinus*- and *mentella*-type larvae and female parents present. The larvae should be preserved immediately after capture and examined as soon as possible.

From our limited knowledge of the vertical distribution of the early stages of redfish larvae, in which the presence or absence of caudal melanophores could be observed adequately, it is likely that these larvae are more abundant in the surface water layers. This applies to the Gulf of St. Lawrence where the larvae, judging by their parents which occur mainly between 100 and 180 fathoms (180–330 m), would be almost entirely of the *mentella* type, as well as to the European redfish larvae (Templeman, 1959). Although they are very likely to be most numerous near the surface, we cannot yet be entirely certain whether the very young stage larvae of *mentella* parents from 200–350 fathoms (370–640 m) are most numerous near the surface or at some intermediate depth.

In the European area, where *marinus* and *mentella* larvae may well differ in caudal melanophore numbers from those of the Newfoundland area, there are, chiefly in the coastward areas, numbers of *Sebastes viviparus* which Tåning's verbal observations indicated were like the American form of redfish in the presence of ventral caudal melanophores in the larvae. *S. viviparus*, however, according to Collett (1880), spawns several months later than *S. marinus* (probably *marinus* type) and presumably is also later in spawning than the *mentella* type of the area. Thus, if Collett's observation is correct it should be possible to take the larval tows early enough to have few, if any, *viviparus* type present. Here, once the late stage pre-extrusion larvae of *marinus* and *mentella* are studied, the offshore plankton samples may also serve to evaluate the numbers of *marinus* and *mentella* larvae and female parents. It may be that in most areas, away from the inshore region, *viviparus* is not numerous enough to provide more than a nuisance amount of larvae; or on studying the *viviparus* larvae, some character may be found which will serve to distinguish them from *mentella* larvae.

SPECIES DIFFERENTIATION AND POSSIBILITIES OF INTERBREEDING BETWEEN MARINUS AND MENTELLA. *Sebastes marinus marinus* and *Sebastes marinus mentella* have many recognizable differences (Lundbeck, 1940; Kotthaus, 1950; Travin,

1951; Andriiashev, 1954; Templeman, 1959), and many other differences have been recorded by us and by other workers but have not yet been published. The differences between the larval samples of the two forms probably provide the best argument yet published towards the case for the existence of a real genetic difference between *marinus* and *mentella*.

From the presence and number of caudal melanophores in samples of *marinus* and *mentella* larvae in the Newfoundland area (Tables III-V), it is easy to believe that there is some interbreeding, but also some means whereby the populations are kept relatively distinct. It may well be that studies of the presence or absence and the numbers of caudal melanophores present in larval samples from *marinus* and *mentella* parents from the same areas of the North Atlantic, will reveal information bearing on the differing amounts of interbreeding, and the relative purity of the *marinus* and *mentella* stocks in the different areas. It is also evident, however, that either there is very little interbreeding or that the offspring of interbreeding parents must be relatively infertile, otherwise the great differences which exist in number of caudal melanophores in larvae of *marinus* and *mentella* parents could not be maintained.

In our Newfoundland samples of larvae (Table IIIA), it may well be argued that the small number of *mentella* larvae without caudal melanophores, and the lone *mentella* female with about half the larvae without caudal melanophores (the typical *marinus* characteristic) indicate the fertilization of only a small proportion of the population of *mentella* females by *marinus* males. Similarly, the fact that all samples of *marinus* larvae have at least some larvae with caudal melanophores (a *mentella* characteristic), and that many of the larval samples from *marinus* female have from one-third to one-half of the larvae with 1 or more caudal melanophores, may be evidence that a higher proportion of the population of *marinus* females in the Newfoundland area are fertilized by *mentella* males than is the case for *mentella* females and *marinus* males.

Once the character of lack of caudal melanophores has been transferred to larvae of the *mentella* females, or presence of caudal melanophores to the larvae of *marinus* females, and if these hybrids are fertile, there would be a gradual diffusion of these and other intermediate characters throughout the *marinus* and *mentella* populations.

Although some redfish populations of intermediate type have been reported (Baranenkova, 1957; Kotthaus and Krefft, 1957), *marinus* and *mentella* types of adults are usually readily distinguished. Apart from the possibility of relative or complete infertility of the progeny resulting from interbreeding of *marinus*- and *mentella*-type redfish, there are a number of factors which should tend to reduce the amount of interbreeding: (a) the main part of the adult population of *mentella* lives, at least during summer and autumn, at a considerably greater depth than that of *marinus* (Kotthaus and Krefft, 1957; Baranenkova, 1957; Templeman and Sandeman, 1957; Templeman, 1959); (b) not only are most *marinus* redfish at a different depth, but it is apparent in the Newfoundland area that these are on rougher, more rocky bottom than *mentella*; (c) the *marinus* type may have a more pelagic habit, and migrate more, especially at the spawning time of the

females (Templeman, 1959), and may thus also have different habits to the *mentella* at the copulation period; (d) *marinus*-type fish grow to a greater final size than *mentella* in the Hermitage Bay area where there is probably about a 10 cm difference in favour of *marinus*; (e) in the area we have studied most — Hermitage Bay — *marinus* females mature sexually at a size about 10 cm greater, and a weight several times as heavy as *mentella*; the largest mature *mentella* females of this area are only about 6 cm larger than the smallest mature *marinus* females; (f) *marinus* females spawn (extrude their larvae) before *mentella* females (several weeks earlier in the Hermitage Bay area).

It seems likely therefore, in the Hermitage Bay area, at least, that *marinus* are ready for fertilization several weeks before *mentella*. It is evident, from the work of Magnússon (1955) and from our own studies over the past ten years, that sperm transfer to female redfish takes places several months before the eggs of the female mature to the clear stage which precedes development. However, it is not absolutely certain whether or not there is for each female a relatively short period for transfer of sperm. Actually, such information as we possess points to an increase in the quantity of sperm in the ovary over a period of several months before the initiation of development of the egg. We cannot be certain, however, how effective a barrier to interbreeding is provided by the slightly different spawning seasons.

For the European area, Collett (1880) says that off the Norwegian coast the spawning of *Sebastes marinus* generally extends from the middle of April to the middle of May, although occasional *S. marinus* with fully developed ova are occasionally met with late in summer. He states also that *Sebastes viviparus*, on the contrary, does not, as a rule, produce its young earlier than July or August. The *S. marinus* referred to by Collett is evidently *S. marinus marinus*, and if in the various areas inhabited by *viviparus* and *marinus* the spawning times are actually different, this factor together with the shallower depth habits, and the much smaller size at sexual maturity and final size of *S. viviparus*, should almost eliminate the possibility of interbreeding between *marinus* and *viviparus*. Because of the still greater depths inhabited by *mentella*, the possibilities of interbreeding between *mentella* and *viviparus* should be even more remote.

In our data there is no evident relationship, either for *marinus* or for *mentella* for the various areas, between the percentage of larvae with caudal melanophores, or the number of caudal melanophores and the size of the parent female.

Although the Northwest Atlantic redfish larvae featured both in Bigelow and Welsh (1925) and Dannevig (1919) have been of the American *mentella* type, all European, Greenland, and Tåning's oceanic larvae (apart from Dannevig's (1919) Oslo Fjord specimen which was probably *viviparus*) have been of the *marinus* type without caudal melanophores. We may feel fairly certain, therefore, that the European *marinus*-type female redfish possess larvae at least most of which have no caudal melanophores. The presence and numbers of larval melanophores in *mentella*-type redfish of the North-central and Northeast Atlantic remain to be investigated.

USE FOR STUDY OF INTERMEDIATE TYPES. In addition to the distinct (at least for adult and for many smaller redfish) *marinus* and *mentella* forms, redfish populations and individuals, intermediate in form between the typical *marinus* and *mentella*, have been reported (Baranenкова, 1957; Kotthaus and Krefft, 1957; Templeman, 1959). Especially when recognizable populations of such redfish are found, the study of the presence and numbers of caudal melanophores in their larvae should provide information on whether these populations are in fact definitely *marinus* or *mentella* or intermediates between them. This type of study can be carried out now in the Newfoundland area. In the North-central and North-east Atlantic, from which such intermediate-form populations have been reported, the value of such a study will depend on whether the samples of larvae from *mentella*-type females in an area can in fact be readily distinguished from those from *marinus*-type females.

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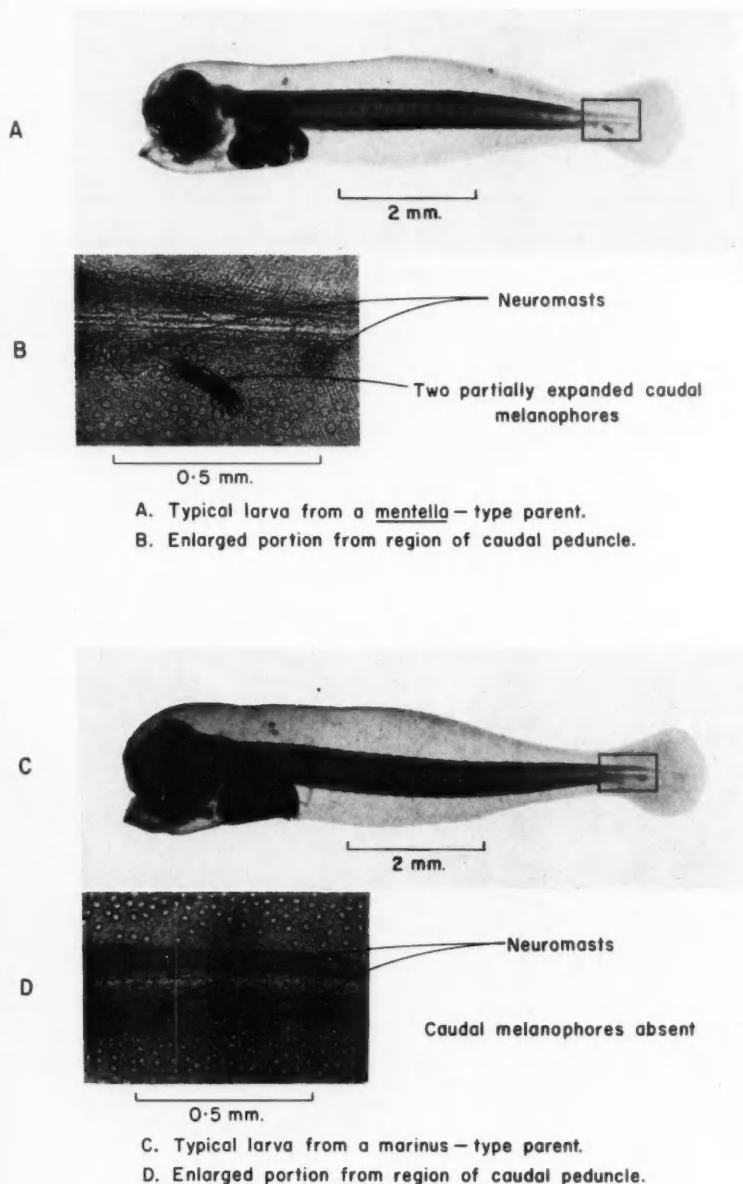


FIG. 1. Typical larvae from *mentella*- and *marinus*-type female redfish parents.

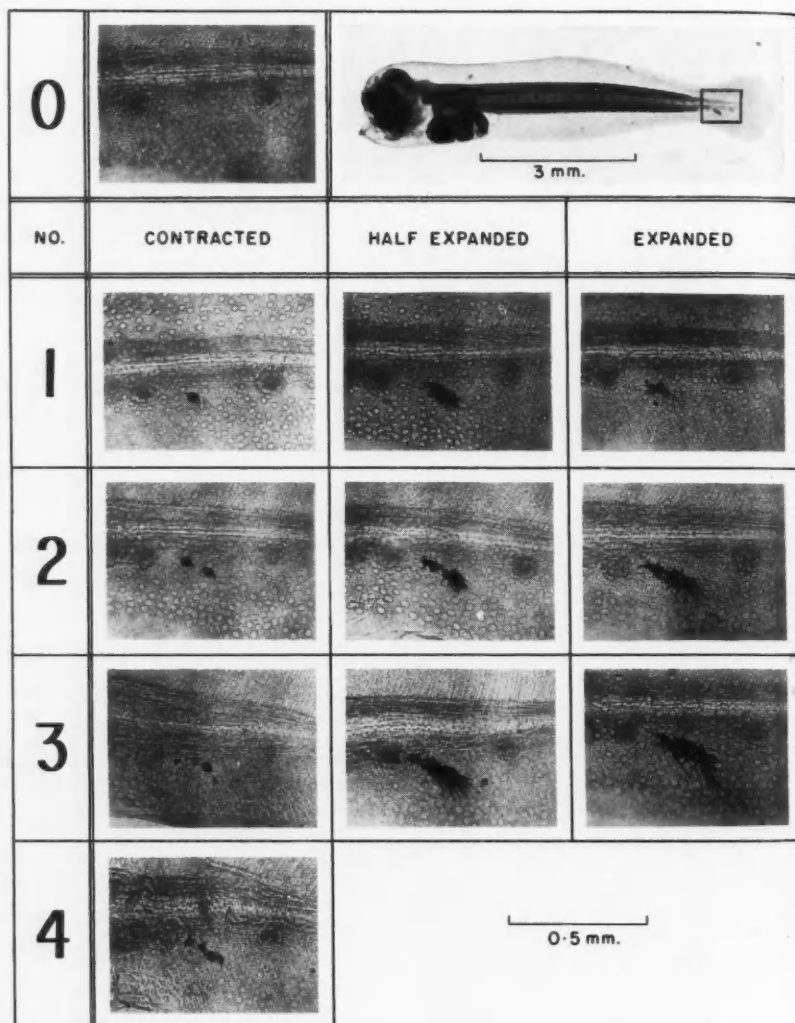


FIG. 2. Enlarged portions of the caudal peduncle region of larvae, showing numbers of caudal melanophores from 0 to 4 at different degrees of expansion. The larvae from which these photographs of caudal melanophores (including that with no melanophores) were obtained, were all taken from a single *mentella*-type parent 36 cm in length, from a depth of 150 fathoms (274 m) at Flemish Cap on June 30, 1958. (The enlarged portions are similar to that in the rectangle in the larva in the upper right hand corner.) In a sample of 120 larvae from this fish, 20 possessed 1 caudal melanophore, 80 possessed 2, 17 had 3, and 3 had 4. A large number of additional larvae were examined before one was found in which caudal melanophores were absent.

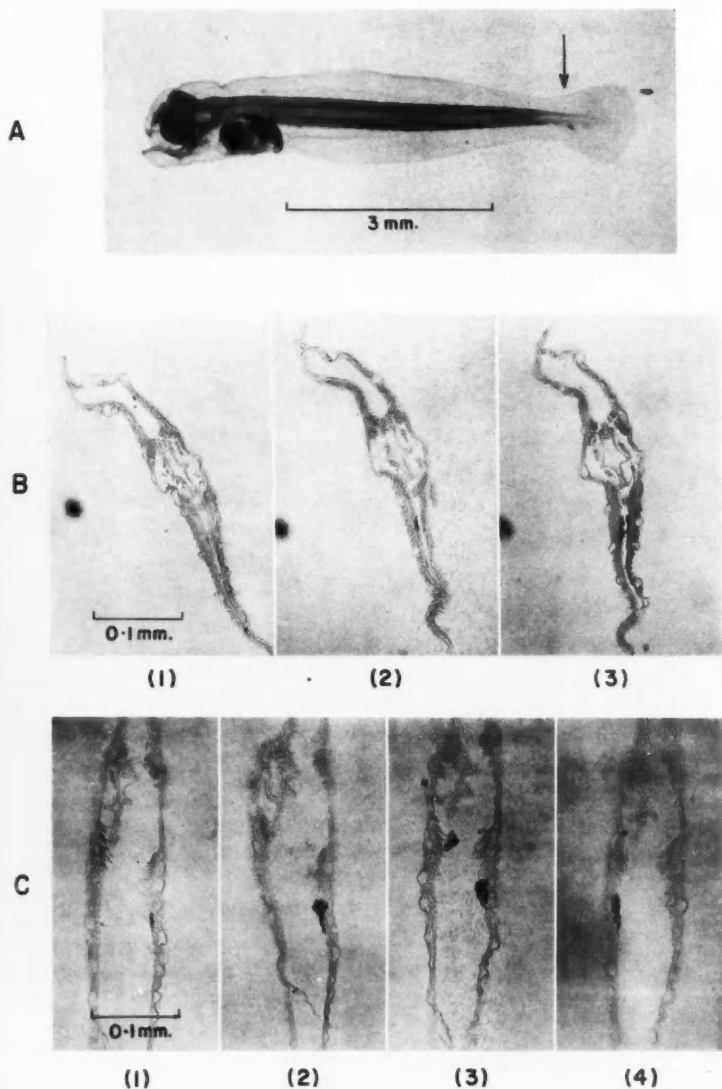


FIG. 3. A. Larva taken from a *mentella*-type parent 36 cm in length. B. Consecutive transverse sections cut at $15\ \mu$ through the caudal melanophore of the larva shown in A. The arrow in Fig. 3 A indicates the region through which the sections were cut. C. Consecutive transverse sections cut at $15\ \mu$ through the posterior caudal melanophore of another larva taken from the same parent fish as that shown in A. (The entire posterior caudal melanophore extends over approximately $75\ \mu$.)

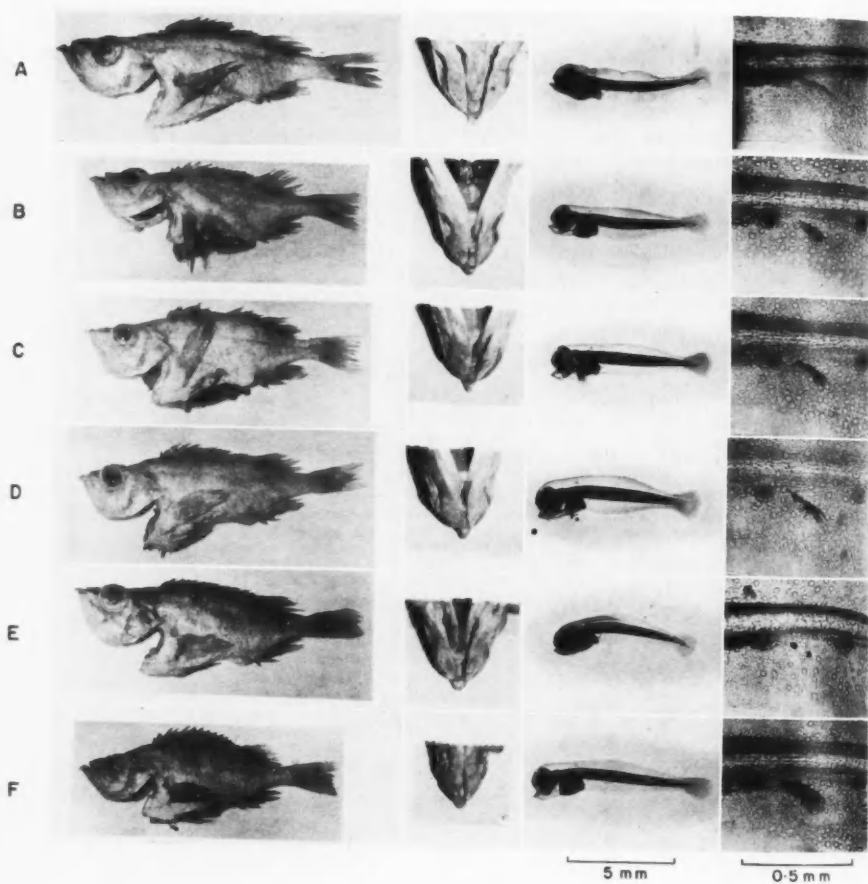


FIG. 4. Larvae from *mentella*-type redfish. (The larvae were picked at random from those possessing ventral caudal melanophores. An enlarged section of the caudal region and the female parent fish are also shown, as well as a ventral view of the lower jaw of the female parent. The position of the caudal enlargements at the right is shown by the rectangles in Fig. 1 and 2.)

				Larvae	
Female parent (<i>mentella</i>)				No. of larvae with one or more caudal melano- phores (120 examined)	No. of caudal melano- phores in 120 larvae
Locality	Date	Depth	Length to midfork caudal fin		
		<i>fath (m)</i>	<i>cm</i>		
A Hermitage Bay	4/VII/58	131-141 (240-258)	41	58	63
B Flemish Cap	30/ VI/58	150 (274)	35	109	157
C Flemish Cap	30/ VI/58	150 (274)	36	120	243
D Flemish Cap	25/ VI/58	200 (366)	37	120	199
E Hermitage Bay	4/VII/58	131-141 (240-258)	37	120	219
F Hamilton Inlet Bank	10/ VI/58	250 (457)	33	120	268

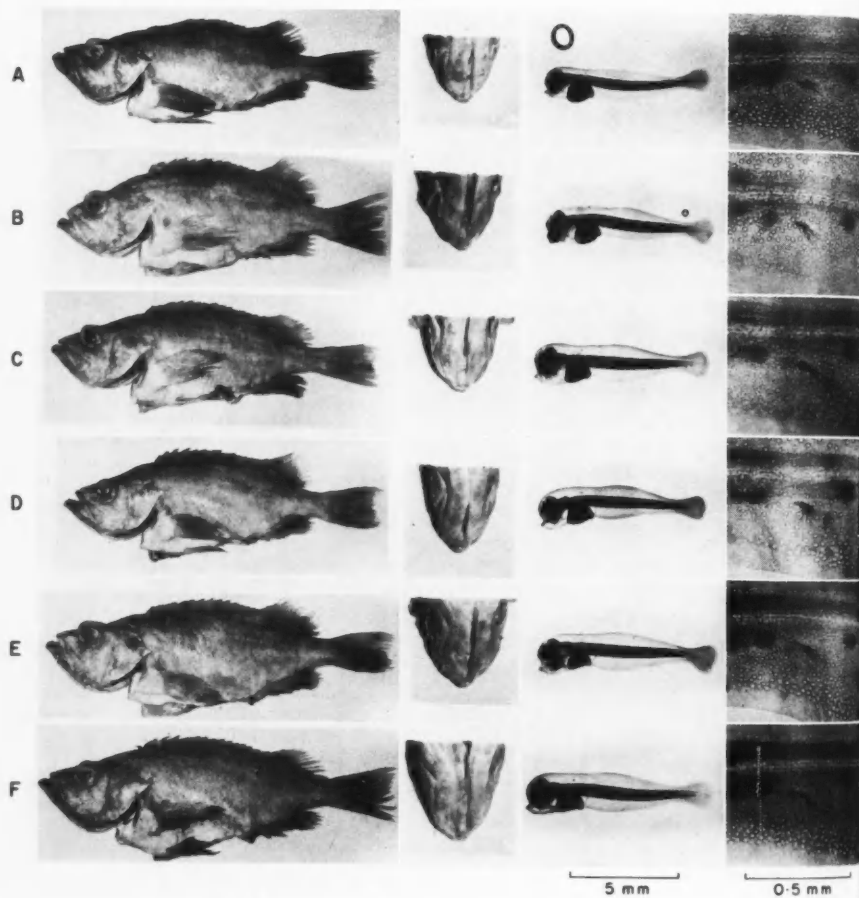


FIG. 5. Larvae from *marinus*-type redfish. (The larvae were picked at random from those possessing ventral caudal melanophores. The enlarged section of the caudal region and the female parent fish are also shown, as well as a ventral view of the lower jaw of the female parent. The position of the caudal enlargements at the right is shown by the rectangles in Fig. 1 and 2.)

Female parent (<i>marinus</i>)				Larvae	
Locality	Date	Depth	Length to midfork caudal fin	No. of larvae with one or more caudal melano- phores (120 examined)	No. of caudal melano- phores in 120 larvae
		<i>fath (m)</i>	<i>cm</i>		
A Hamilton Inlet Bank	10/VI/58	250(457)	42	3	3
B Hamilton Inlet Bank	10/VI/58	250(457)	43	10	10
C Hamilton Inlet Bank	10/VI/58	250(457)	42	22	22
D Hamilton Inlet Bank	10/VI/58	250(457)	42	37	39
E Hamilton Inlet Bank	10/VI/58	250(457)	45	52	53
F Hamilton Inlet Bank	10/VI/58	250(457)	46	61	67

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Keeping Quality of Pacific Coast Dogfish¹

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ABSTRACT

Pacific coast dogfish (*Squalus suckleyi*) were held 21 days in ice and in refrigerated sea water with and without added chlortetracycline, viable bacterial counts and volatile bases being determined periodically. Viable bacteria increased sharply after about 14 days but the muscle pH values showed little or no increase. No appreciable increase in the total volatile base or trimethylamine content of the muscle was noted until the fish were stored for more than 2 weeks, and then the increases observed were comparatively small.

INTRODUCTION

IT APPEARS to be generally believed that the flesh of dogfish and shark species spoils very rapidly, emitting a strong odour of ammonia a few days after catching. This belief is largely in accord with the available literature which describes a spoilage pattern supposedly typical of elasmobranch fishes in which the muscle urea is hydrolysed by bacterial urease to produce from 400 to 600 mg of ammonia per 100 g of fish flesh. Indeed, under some conditions it appears that ammonia is formed in concentrations sufficient to cause the muscle to assume an alkaline reaction, which in turn occasions cessation of bacterial growth and the accompanying trimethylamine oxide reduction (Elliott, 1951; Simidu and Oisi, 1951, 1952; and many others). Some of the results of these investigators were obtained using eviscerated whole fish spoiling at temperatures above 5°C, or with minced samples. Simidu and Oisi (1952) noticed two distinct stages in the decomposition of elasmobranch flesh. Working with muscle stored at 5 to 10°C they observed a rapid evolution of ammonia until the quantity reached 400 to 500 mg per 100 g of flesh, after which it ceased for a time and then resumed vigorously. The second stage was characterized by a peculiar putrid odour which differed from the ammoniacal odour of the first stage. At temperatures between -1° and +3°C the first stage was not observed even after 10 or 15 days, a putrid odour developing instead at about 12 days.

The purpose of the present investigation was to determine the length of time Pacific coast dogfish could be stored under what are usually considered ideal conditions without undergoing serious bacterial spoilage.

EXPERIMENTAL

Sixty live dogfish were beheaded, eviscerated, thoroughly washed with running tap water, divided into four groups and held under the following conditions: (a) in crushed ice; (b) in crushed ice after a previous dip in a 50-ppm chlortetracycline (CTC) solution; (c) in refrigerated sea water; (d) in refrigerated sea water containing 10 ppm CTC.

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The iced fish were held in galvanized tanks contained in an insulated box; they were kept completely surrounded by an excess of crushed ice throughout the course of the experiment. The sea water was maintained at -1°C in tanks as described by Baker, Southcott and Tarr (1958). At intervals, fillets were cut from a single fish from each treatment, skinned and used for bacteriological and chemical determinations.

The skinned fillets were placed individually in new polyethylene bags. One fillet was homogenized for the volatile base determinations and the other incubated 18 hours at 10°C . The latter was cut into small pieces and 100 g was homogenized before making appropriate dilutions for viable bacterial counts. These plate counts were made in duplicate using the following medium at pH 6.5: Bacto peptone, 0.4%; yeast extract, 0.1%; FePO_4 , 0.001%; agar, 1.5% dissolved in 80% modified artificial sea water. A 72-hour incubation at 25°C was employed.

The muscle pH was determined with a Beckman Model G pH meter, using calomel and glass electrodes.

Total volatile base nitrogen (TVB) and trimethylamine nitrogen (TMA) were determined immediately after sampling. Flesh (50 g) from the head end of a fillet was made to 250 ml with 99% ethanol, blended for 2 minutes using a Servall Omnimixer and allowed to stand for 1 hour before filtering through glass wool. The residue was dispersed in 250 ml of 80% ethanol, permitted to stand 1 hour and filtered. The filtrates were combined and a 10-ml aliquot was taken and tested for TVB and TMA according to the distillation procedure of Ronold and Jakobsen (1947). When the work was initiated it was anticipated that comparatively high concentrations of ammonia would be formed, and hence the sampling technique was designed to determine concentrations of 5 mg/100 g or higher.

RESULTS

The considerable "scatter" in the results which are given in Tables I and II is typical of that which is found when fish of about the same *post-mortem* age

TABLE I. Changes in viable bacteria and pH in muscle of eviscerated dogfish held in ice and in refrigerated sea water.

Days storage	Ice		Ice (CTC dip)		Sea water		Sea water + 10 ppm CTC	
	pH	Bact. (millions per gram)	pH	Bact. (millions per gram)	pH	Bact. (millions per gram)	pH	Bacteria (millions per gram)
2	6.4	0.006	6.7	0.002	6.2	0.002	6.2	0.0007
6	6.3	0.013	6.5	...	6.2	0.25	6.4	0.042
7	6.3	0.48	6.2	0.004	6.6	1.2	6.1	0.038
8	6.2	1.13	6.1	0.002	6.3	2.7	6.4	0.19
9	6.3	0.91	6.2	0.013	6.3	1.4	6.6	0.13
10	6.2	3.5	7.0	0.008	6.2	1.5	6.1	0.65
11	6.4	3.8	6.1	0.048	6.3	0.75	6.1	0.62
12	6.6	15.0	6.4	0.45	6.3	2.5	6.1	3.5
13	6.4	8.4	6.3	8.8	6.3	8.5	6.1	5.8
16	...	...	6.8	15.0	6.5	6.6	6.5	6.2
18	6.8	74	6.7	35	6.7	4.1	6.6	4.8
21	7.4	150	6.6	64	6.8	19.0	6.7	31

TABLE II. Total volatile base and trimethylamine nitrogen (mg/100g) in muscle of eviscerated dogfish held in ice and refrigerated sea water.

Days storage	Ice		Ice (CTC dip)		Sea water		Sea water + 10 ppm CTC	
	TVB	TMA	TVB	TMA	TVB	TMA	TVB	TMA
2	10.0	0	10.0	0	7.5	0	13.0	0
6	10.0	0	10.0	0	5.0	0	6.0	0
7	8.5	2.5	9.5	3.5	7.5	2.5	5.5	3.5
8	7.5	0	14.5	2.5	6.0	0	7.5	0
9	12.5	2.5	8.5	2.5	9.5	3.5	6.0	0
10	8.5	2.5	5.0	0	7.5	0	8.5	2.5
11	9.5	3.5	9.5	3.5	11.0	5.0	7.5	...
12	13.5	3.5	13.5	3.5	12.5	5.0	13.5	3.5
13	12.5	5.0	9.5	3.5	11.0	6.0	12.5	5.0
16	...	...	13.5	6.0	24.5	17.5	13.5	3.5
18	17.0	0	10.0	0	18.0	5.0	12.5	2.5
21	18.5	0	13.0	0	18.0	13.0	20.0	10.0

are stored in ice or refrigerated sea water and individual fish are removed at intervals.

Viable bacterial counts, particularly with the iced, untreated fish, began to increase sharply after about 14 days. The CTC treatment delayed bacterial growth noticeably with the iced fish, but had no appreciable effect with those held in refrigerated sea water. The pH values showed little or no increase. The TVB content of the muscle, which was initially about 10 mg/100 g, remained at about this level throughout the first 11 or 12 days of the experiment, and even after 3 weeks had not increased very markedly in most instances. The TMA content remained low throughout the experiment, values in excess of 5 mg/100 g being recorded after 13 days storage in only four of all fish examined. Organoleptic examinations indicated that the flesh of fish from all treatments became soft after about 2 weeks storage. After about 16 days fish not treated with CTC developed a stale odour and were putrid after 19 days. Those treated with CTC developed a stale odour after about 19 days. After 21 days all fish were definitely unacceptable, though those treated with CTC were sour rather than putrid. No definite ammoniacal odour was detected on any of the first throughout the 21-day storage period.

The whole experiment was repeated under almost identical conditions, the fish being stored 25 days with very similar results. The findings are of interest in that they indicate that dogfish, when stored under nearly ideal conditions, appear to spoil no more rapidly than most other sea fish. Shewan (1950) observed a rather high initial ammonia nitrogen content in fresh dogfish flesh (about 10 mg/100 g), and the present results, assuming that ammonia is represented by the difference between TVB and TMA, verify this observation. However, in contrast to results of many other workers, very high ammonia concentrations have not been found even after fairly prolonged storage. The reason for this is not known, but it may lie in an absence of a dominant population of urease-forming bacteria, or in inability of such organisms to develop well at 0° or -1°C. In

general, literature concerning the utilization of dogfish or shark for human consumption refers to the undesirable ammoniacal flavour encountered even with fresh specimens where the low ammonia content could hardly in itself be responsible. However, urea itself is said to be detected organoleptically when present in a concentration of only 0.007% (Gavaudan and Schutzenberger, 1950). Also, it is not unlikely that salivary urease (Ballantyne *et al.*, 1951, 1952) may occasion formation of organoleptically detectable amounts of ammonia from the urea which may occur in up to 2% concentrations in dogfish muscle (Shewan, 1950).

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Sagitta lyra, a biological indicator species in the subarctic waters of the eastern Pacific Ocean¹

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ABSTRACT

In the Gulf of Alaska the chaetognath, *Sagitta lyra*, was most frequently found in areas where the temperature at 150 m exceeded 6°C and the salinity exceeded 33‰. Water of this character was mainly associated with a northward intrusion of warm water past the Canadian coast. Comparison of surface gillnet catches of salmon with occurrence of *S. lyra* showed that when *S. lyra* was present in the zooplankton, the salmon catch was small and when it was absent the catches of salmon could be quite large. This change in catch was even observed (on two occasions) on successive days at a station where the physical properties of the water did not change detectably.

INTRODUCTION

THIS PAPER deals with the distribution of the chaetognath, *Sagitta lyra* Krohn in the Gulf of Alaska with relation to the oceanography and salmon catches within the area. Past studies of chaetognaths have shown that they are often useful indicators of the presence of a particular water mass. Hence they could conceivably be useful in delimiting the distribution of Pacific salmon (*Oncorhynchus* spp.) in the ocean.

One of the first examples of the use of chaetognaths as biological indicators was described by Meek (1928). He found that indigenous North Sea water off the Northumbrian coast had, as one of its plankton components, *S. setosa*. However, at times *S. setosa* was replaced by *S. elegans*. He was able to show that occurrence of *S. elegans* was related to intrusion of North Sea water which had been mixed with oceanic water moving along the coast, pushing *S. setosa* type water out. Russel (1939), Fraser (1952) and more recently Bieri (1959) have reviewed the role of chaetognaths as indicator species. Bieri published an excellent paper describing the distribution of the chaetognaths of the Pacific Ocean. Unfortunately, he had only a few samples from the Gulf of Alaska, and also, he lacked adequate samples of *S. lyra* to show its distribution in the Pacific. Hida (1957) defined three faunal regions in the upper 200 metres of the central North Pacific on the basis of zooplankton abundance. Within these regions he found characteristic chaetognath species. *S. elegans* and *Eukronia hamata* occupied the subarctic water mass, *S. lyra* and *S. minima* the North Pacific Current and *S. hexaptera*, *S. serratodentata*, *S. bipunctata* and *Pterosagitta draco* the Pacific central water mass. Lea (1955) reported finding *S. lyra* amongst the Chaetognatha taken in plankton tows from the coast of British Columbia. Sund (1959) also establishes the presence of *S. lyra* in the Gulf of Alaska, but again there were insufficient samples to show the distribution of the species.

The data used in this report were collected by Canadian research vessels operating in the northeast Pacific Ocean as part of the Canadian contribution to

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the work of the International North Pacific Fisheries Commission. Five species of Chateognatha have been identified in the examination of the material. In order of frequency of occurrence these were *S. elegans*, *Eukronia hamata*, *S. lyra*, *S. decipiens* and *S. planctonis*. Occurrence of the last two species, while sporadic and infrequent, was limited to an area off the British Columbia coast during summer. The first two species occurred throughout the year over the entire Gulf. *S. lyra* was limited to an area generally south of 55°N Latitude and east of 145°W Longitude.

MATERIALS AND METHODS

Data for this report were obtained mainly from vertical plankton tows from 150 m during 1957 and 1958 with the North Pacific standard nylon net. (For details regarding the net see Reid, 1956, and Motoda *et. al.*, 1957.) The data (physical, chemical rough zooplankton analyses, and fishing data), together with details of analyses are available in Fisheries Research Board of Canada Manuscript Reports, Oceanographic & Limnological Series, Nos. 4, 14, 16, 17, 28, 29 and 31, and in three earlier "Data Records" not numbered in this Series. Nearly 3000 samples have been examined from an area generally north of 50° N and east of 155° W. The collections were mostly made during summer months, May to August, when the exploratory salmon fishing vessels were under charter. Limited winter collections were made for both years from oceanographic vessels. Also, collections made at 6-week intervals were available from Weather Station "P" (50°N Lat., 145°W Long.). Additional observations between 100 m and the surface were made in 1958 from the exploratory salmon fishing vessels by (a) tows with a modified version of the Isaacs-Kidd midwater trawl (Aron, 1958); (b) horizontal plankton tows with the North Pacific standard nylon net and (c) a night-light net.

In the laboratory analysis of the zooplankton samples, organisms larger than 4 cm were generally picked out. The remaining material was examined under a low power microscope and the proportions of the major constituents estimated in terms of the total wet weight of the sample. Subsequently, the wet weight of the samples was determined and the wet weight of the sample and its constituents

TABLE I. Classification of plankton samples from the Gulf of Alaska with respect to temperature, salinity, and the presence or absence of *Sagitta lyra*. A: total samples taken at the indicated temperature and salinity; B: number of samples containing *S. lyra*.

Temperature intervals	Salinity intervals (in parts per thousand)									
	32.00-32.49		32.50-32.99		33.00-33.49		≥33.50		Total	
	A	B	A	B	A	B	A	B	A	B
(°C)										
8.0+	0	—	4	2	0	—	5	5	9	7
7.0-7.9	1	0	1	0	12	9	40	28	54	37
6.0-6.9	3	2	7	1	41	23	71	38	122	64
5.0-5.9	0	—	9	0	32	7	54	10	95	17
4.0-4.9	0	—	0	—	11	2	34	0	45	2
3.0-3.9	0	—	0	—	6	1	11	2	17	3
Total	4	2	21	3	102	42	215	83	342	130

calculated per 1000 m³ of water, with no adjustment for filtering efficiency of the net. The dominant copepod, euphausiid and chaetognath species were identified whenever possible.

RESULTS

Sagitta lyra AND PHYSICAL CONDITIONS

The occurrence of *S. lyra* was examined in relation to the temperature and salinity recorded at 150 m (Table I). The data indicate that in over 50% of the stations *S. lyra* occurred most commonly where the salinity was more than 33‰ and the temperature was higher than 6°C (Fig. 1.) It occurred in all the

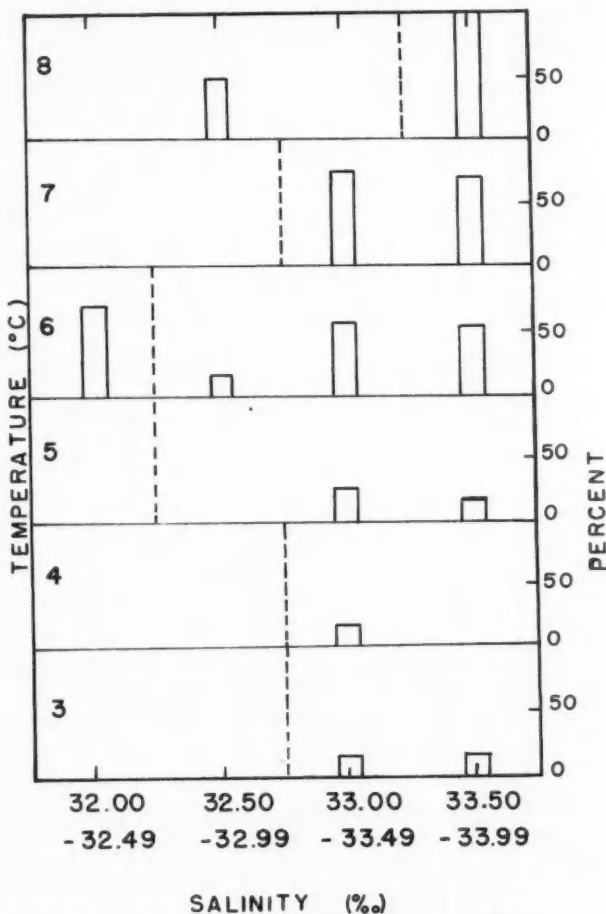


FIG. 1. Percentage occurrence of *S. lyra* in relation to temperature and salinity at 150 m. Points to left of dotted line are based on less than 5 observations (see Table I).

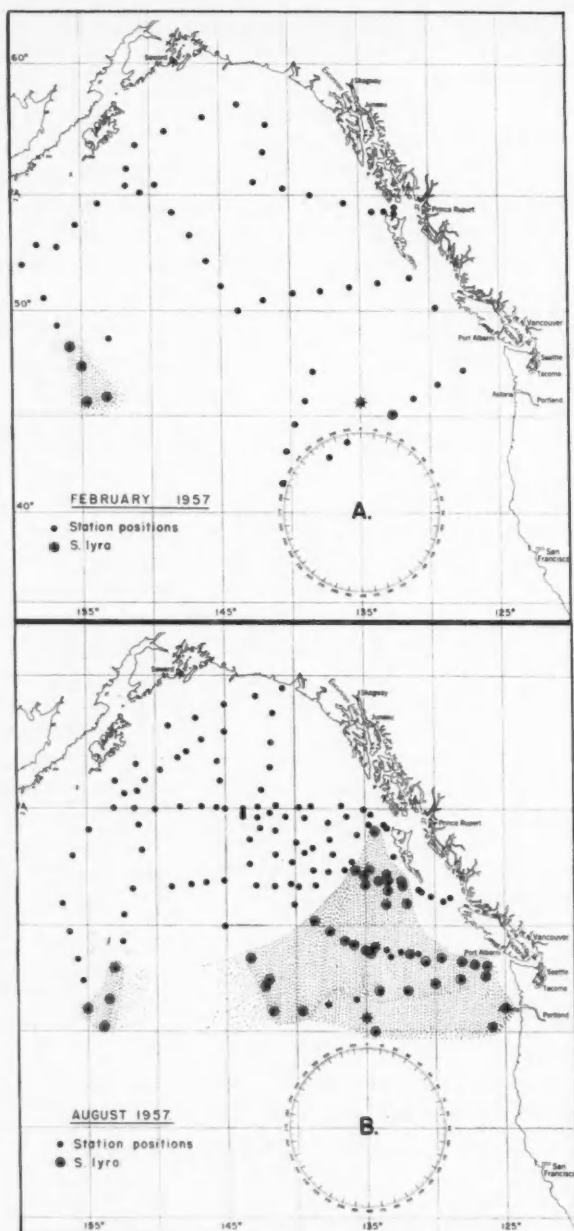


FIG. 2, A and B. Distribution of *S. lyra* in the northeast Pacific Ocean during February and August, 1957.

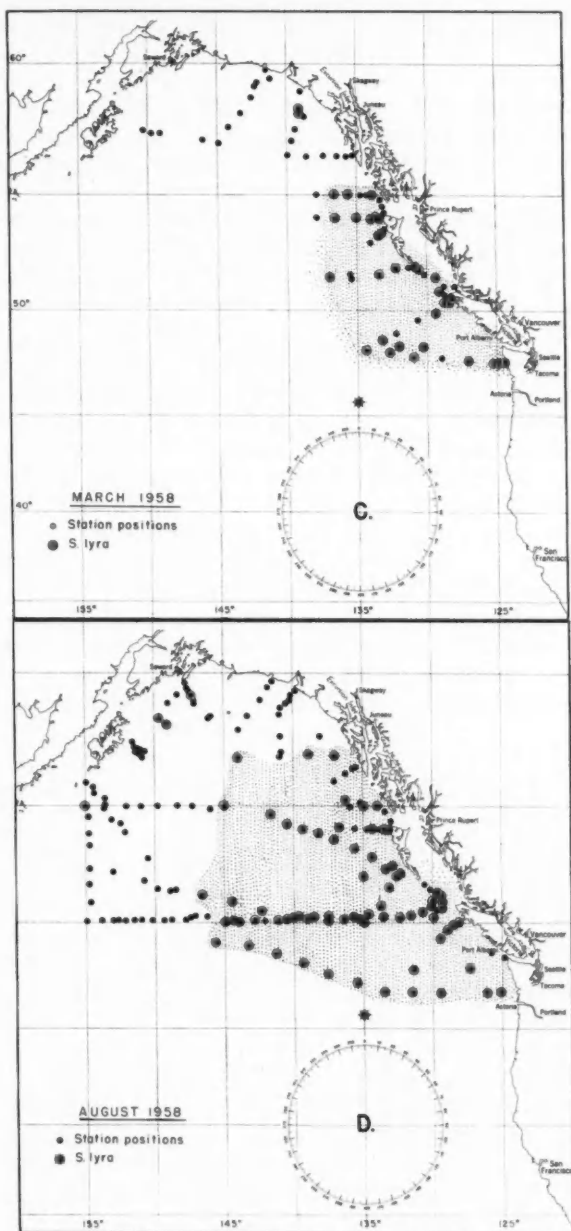


FIG. 2, C and D. Distribution of *S. lyra* in the northeast Pacific Ocean during March and August, 1958.

samples where the salinity was greater than 33.5‰ and the temperature was greater than 8°C. At progressively lower salinities or temperature, it was less likely to be present.

At Weather Station "P" (50°N Lat., 145°W Long.), a series of vertical tows made between 500 m and the surface revealed that *S. lyra* occurred more frequently above than below 300 m and only on one occasion during the two years did it occur in tows above 100 m. However, Canadian exploratory salmon fishing vessels in 1958 commonly collected *S. lyra* between the surface and 100 m in horizontal hauls along 50° N to the west as far as 145° W. North of 50° N, *S. lyra* was taken only once in a horizontal haul, at 55° N 150° W, in a sample from 60 m. All other *S. lyra* taken in the northeastern Pacific were from vertical tows from 150 m depth.

Since the studies of *S. lyra* were begun, there has been a marked change in its distribution in the northeastern Pacific Ocean (Fig. 2). The Figure shows that in February of 1957, no *S. lyra* were found north of 49° N. In August 1957, they were found off the Canadian west coast as far as 54° N, and in 1958 the region they occupied extended both to the north and west. A striking feature of their distribution, was their absence, with one exception, in the Gulf of Alaska west of 145° W.

Sagitta lyra AND SALMON DISTRIBUTION

The data from 1957 and 1958 on occurrence of salmon and *S. lyra* were compared. The 1957 data were of limited value, as only a few plankton observations were made during the period a fishing station was occupied. In 1958, the plankton was sampled both during and after each fishing operation. Figure 3

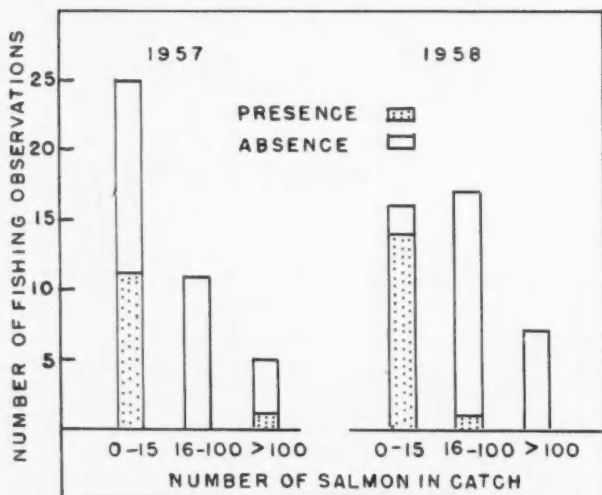


FIG. 3. Occurrence of *S. lyra* with respect to size of salmon catch.

shows an inverse relation between size of salmon catch in surface gillnets and presence of *S. lyra*. This may be demonstrated further at two fishing stations which were occupied for several days. One, at 55° N 135° W, was occupied from June 13 to 16. The daily salmon catch was 3, 1, 158 and 23 respectively. *S. lyra* were present in the plankton samples the first two days but absent during the last two. On the other occasion, at 50° N 130° W, two vessels were fishing about 20 miles apart for 3 days. The catches for one vessel were 13, 102 and 14. *S. lyra* was absent only on the night of the large catch. At the second vessel, the daily catches were 13, 2 and 0; *S. lyra* was taken in all plankton tows for these 3 days. At each position the physical features of the water column remained relatively constant throughout the fishing period.

SOURCES OF ERROR

Some qualifications should be pointed out. The data, resulting largely from 150 m vertical tows, are the product of a relatively small amount of water being sampled, approximately 24 m³ each tow. Rough counts made of *S. lyra* in samples from what was considered essentially *S. lyra*-type water are shown in the following table. More than 90 of the samples had less than 10 individual *S. lyra*. With the relatively low number of *S. lyra*, it would be expected that through sampling variability alone some samples would contain no *S. lyra*. Another factor contributing to the sampling error was the seasonal variation in abundance of *S. lyra* due to its life history. The larger collections were made in the summer, being composed of small, 10–40 mm, immature specimens, while in the winter collections they were over 40 mm in length in stages of advancing maturity. Thus absence of *S. lyra* is not as significant as its presence. This must, of course, be particularly true for samples bordering or within *S. lyra*-type water.

TABLE II. Frequency distribution of the occurrence of *S. lyra*.

Number of individuals	0	1–5	6–10	11–25	26–49	50+
Number of samples	10	52	32	35	7	3

Also, there is the problem of whether or not *S. lyra* were distributed homogeneously within their three-dimensional environment. In attempting to correlate the distribution of *S. lyra* with measurements of its environment, it must be recognized that the depths at which it was taken in the vertical tows are not known. For example, the range of values of water characteristics, such as salinity or temperature, to a depth of 150 m may be greater than the range of values found at a particular depth over the whole geographical area sampled. With temperature, there is the additional problem of seasonal heating and cooling in the upper 125 m. With respect to salinity, only 7% of the observations were made where the salinity at 150 m was less than 33.00‰, so absence of *S. lyra* from the lower-salinity water could possibly be an expression of sampling variability.

For this paper, since the data permit only the consideration of absence or presence of *S. lyra*, the following assumptions have been made as a matter of convenience: a) the sampling error, while very real, has not had any systematic

bias; b) *S. lyra* are regularly present in their normal environment and, hence, c) values of water characteristics at 150 m, a depth which is below the effect of seasonal variations, reflect the origin of the water of the upper 150 m.

DISCUSSION

With respect to vertical distribution, the observations made by the Canadian research vessel and in the literature suggest that *S. lyra* is more abundant at some depths than at others. Fraser (1952) has described *S. lyra* as a moderately deep, oceanic species of warm-water origin occurring most frequently at depths between 500 and 1000 m in the Scottish plankton. Off California, Michael (1911) found *S. lyra* to be distributed between 46 and 460 m. Hida (1957) noted it was taken more frequently in oblique tows from 40 m than from 140 m. In the northeastern Pacific, *S. lyra* was taken between the surface and 300 m. In horizontal tows it was taken in greatest numbers at depths of 60 m or more. The observations made of *S. lyra* in the North Pacific suggest that it occupies a much shallower domain than that reported by Fraser for the Scottish waters. Fraser found *S. lyra* to occur most frequently where the temperature was between 7 and 11°C and the salinity was greater than 35‰. The present data, which may not be typical for their normal range, indicate that it occurred most commonly where the highest temperatures and salinities in the Gulf were found—that is, in the region where the temperature at 150 m was greater than 6°C and the salinity was greater than 33‰. The few observations on the vertical distribution of the chaetognath indicate that they are not necessarily centred about a depth as great as 150 m. In fact it is possible that they are concentrated at considerably shallower depths. They then would be associated with correspondingly lower salinities and a wider range of temperature. However, the convenience of using a reference depth below the seasonal range of temperature outweighs the importance of their vertical distribution, at least until such time as more data are available.

In common with other zooplankton, *S. lyra* is transported by ocean currents. In the northeastern Pacific the Sub-Arctic Current moves slowly eastward past Station "P". Between Station "P" and the coast it splits, forming two branches. One branch flows northward, forming the Alaska Gyral, the other, known as the California Current, flows southward (Sverdrup *et al.*, 1946, pp. 722–725). Evidence has been recently presented demonstrating intrusion of warm water off the British Columbia coast (Tully *et al.*, in press). The divergence of the Sub-Arctic Current which previously occurred between Station "P" and the coast at about Latitude 48°N, shifted to about 45°N. Also, part of the water which formed the California Current has been incorporated into the Alaska Gyral. This change has been observed from the progressive northward shift of temperature and salinity isopleths and dynamic height anomalies since 1957.

Of particular interest is Fig. 4 (from Tully *et al.*), in which temperature has been plotted on a σ_t surface² of 26.60, showing the extent of the warm water

² σ_t or sigma-*t* — a measure of water density, defined as 1000(Specific gravity - 1). This indicates the sample's excess of weight, in mg per cc, over that of pure water weighing 1 g per cc.

intrusion (hatched area). The σ_t surface of 26.60 lies well below effect of the seasonal temperature cycle. It ranges between 125 and 225 m, roughly approximating the reference depth of 150 m used in comparing occurrence of *S. lyra*

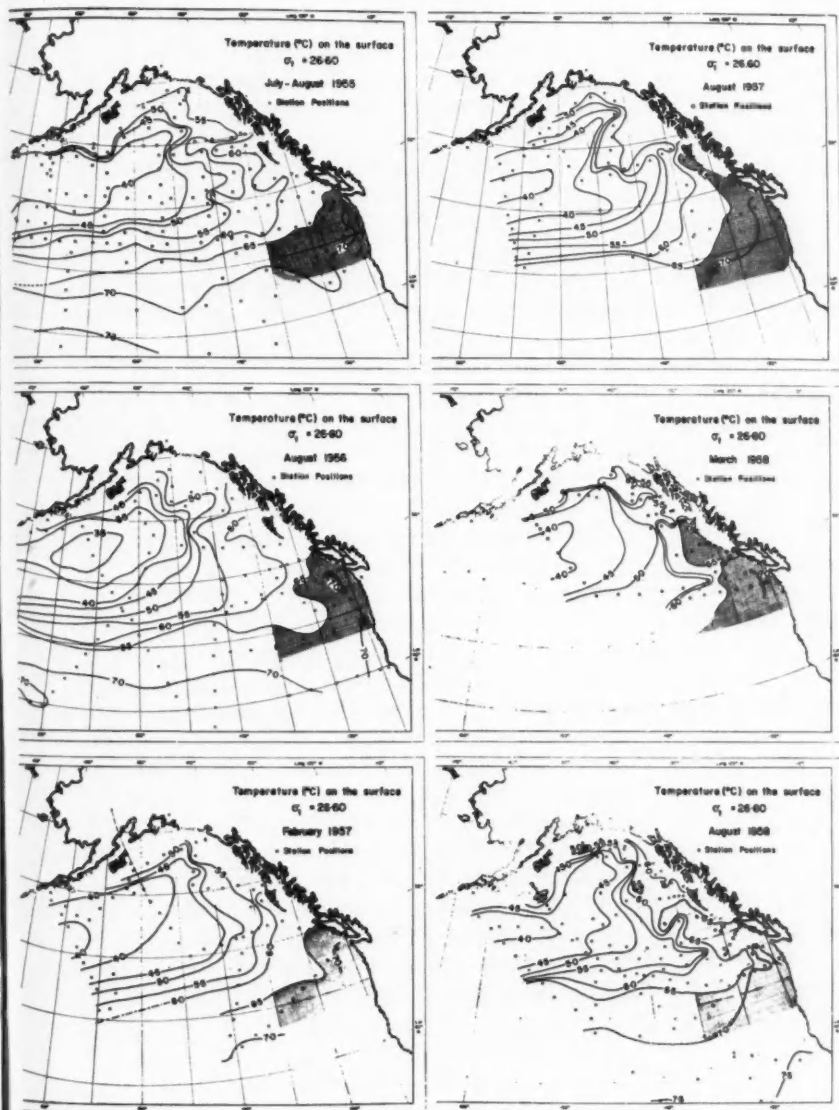


FIG. 4. Temperature on σ_t surface of 26.60 (from Tully *et al.*, in press).

with temperature and salinity. The data presented in Fig. 4 show that the warm water, defined in this case as greater than 6.5°C , has spread over an increasingly large area, notably in 1958. The distribution of *S. lyra* presented in Fig. 2 suggests that the intrusion extends further than is shown by the plot of temperature in Fig. 4. This is to be expected as the plot shows only the extent of the intrusion below the depth of seasonal warming. However, this does not indicate the full extent of the intrusion, which was greatest near the surface. As can be seen from both the distribution of *S. lyra* and the temperature plots, the extent of the intrusion differs between winter and summer for each of the years. This variation is not entirely the result of changes in oceanographic conditions. Part, at least, must be attributed to the fact that winter observations were too few to provide a good description of winter distribution. However, in spite of this and the complexities of sampling a changing population, the extent of the warm water intrusion does vary seasonally as was shown by the physical data and the relatively consistent occurrence of *S. lyra* off the west coast. The isolated occurrences of *S. lyra* seen in 1958 about the periphery of the Gulf (Fig. 2) serve to emphasize another feature related to the warm water intrusion. As may be expected, elements of the intruded water break away and are incorporated into the Alaska Gyral system, becoming mixed with the indigenous subarctic water of lower temperature and salinity. The physical properties used to identify the intruded water become increasingly difficult to observe as a result of the mixing. However, the presence of *S. lyra* provides another means whereby these elements can be recognized.

The coincidence of low salmon catches with the presence of *S. lyra* is particularly interesting. The question arises as to whether the fish were responding to some physical factor such as temperature or to some other difference in the quality of the water. Manzer (MS, 1958) has found a correlation between the depth of the 5, 6, and 7°C isotherms and the numbers of immature chum salmon caught in surface gillnets. The larger catches were made where the $5-7^{\circ}$ isotherms were close to the surface. He suggested that these isotherms might represent the lower limit of preferred temperature. The fish would be more concentrated where the isotherms were shallow and hence more liable to capture in surface nets than where the isotherms were deep. In effect, this relationship is the same as that shown for *S. lyra* and the salmon catches, as *S. lyra* were likely to be absent from a sample when the temperature at 150 m was less than 6°C , i.e. where the $5-7^{\circ}$ isotherms approached the surface. However, there are also the two coincidences of salmon catches varying according to the presence or absence of *S. lyra* at fishing stations which were occupied on successive days. On these occasions, the physical characteristics, typical of *S. lyra*-type water, were constant throughout all the days. It is these latter observations which suggest that the salmon may be responding to some quality of the water other than temperature or salinity.

CONCLUSIONS

- (1) The occurrence of *S. lyra* in the zooplankton of the northeastern Pacific Ocean denotes water having a more southerly origin than that which usually enters the Alaskan Gyral system.

(2) The presence of *S. lyra* may be particularly useful in describing the extent and movement of the warm water after it has become mixed.

(3) There is an inverse relationship between the numbers of salmon caught in high-seas surface gillnets and the occurrence of *S. lyra*. This relationship warrants further study as it holds great promise for throwing light on the movements of salmon, particularly in years of anomalous oceanographic conditions.

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Marine and Freshwater Fishes of the Miramichi River and Estuary, New Brunswick¹

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ABSTRACT

The Miramichi is the largest river in northeastern New Brunswick. The watershed covers an area of about 3,500,000 acres. Its waters support commercial fisheries valued at about \$1,250,000 in 1952 and 1953. The commercial fisheries are located in the tidal waters which extend inland about 50 miles. The fresh waters extend inland about another 100 miles. Water temperatures range from -1.6°C in winter to 25°C in summer and the salinities from 0‰ to 30‰.

Thirty-eight families represented by at least 78 species of fishes have been found in the waters of the Miramichi system. Of the species, 53 are marine, 7 anadromous, 1 catadromous, and 17 freshwater.

INTRODUCTION

THE MIRAMICHI is the largest and most important river system of northeastern New Brunswick. Not only does it provide access to rich timber holdings, but its waters support commercial fisheries valued at about \$1,250,000 in 1952 and 1953. The lobster fishery made up about 31% or \$383,000. The smelt fishery averaged about 21% or \$251,000 and oysters 14% or \$170,000. Gaspereau or alewife, quahaug, and the commercial Atlantic salmon fishery each yielded 8 to 9% or \$100,000. The sport fishery for Atlantic salmon in this river is the largest of any in Canada and is at least as valuable as the commercial fishery or may even be several times as great. The remainder of the Miramichi commercial fisheries include soft-shell clam, tomcod, herring, bar clam, plaice, and cod in descending order of value.

THE PHYSICAL FEATURES

The Miramichi River extends inland about 100 miles from the head of tide and drains an area of almost 5,500 square miles or 3,500,000 acres. At the mouth of the River is Miramichi Bay. It is roughly triangular in shape, 15 miles long, and is separated from the outer estuary by a chain of islands. The outer estuary extends about 8 miles out from this chain of islands to a line joining Escuminac Point on the southeast to Blackland Point on the northeast (Fig. 1). The maximum depth in the outer estuary is 10 fathoms and within the Bay 8 fathoms. Most of the Bay is only 2 to 3 fathoms deep with a deeper ship channel running through it. The main Miramichi River, about a half mile wide with depths of 5 to 7 fathoms, extends inland from the head of the Bay to Newcastle, a distance of 15 miles. At this point, the River divides into two main branches, the Northwest and Southwest Miramichi which are tidal for another 15 miles inland.

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Most of the watershed is in the Carboniferous and Pre-Carboniferous zones with sandstone and shale making up the greater part of the soil. The shores of the estuary are low but along the main Miramichi River some sections rise from 25 to 50 feet in height. Small areas of the headwaters run through Devonian granite.

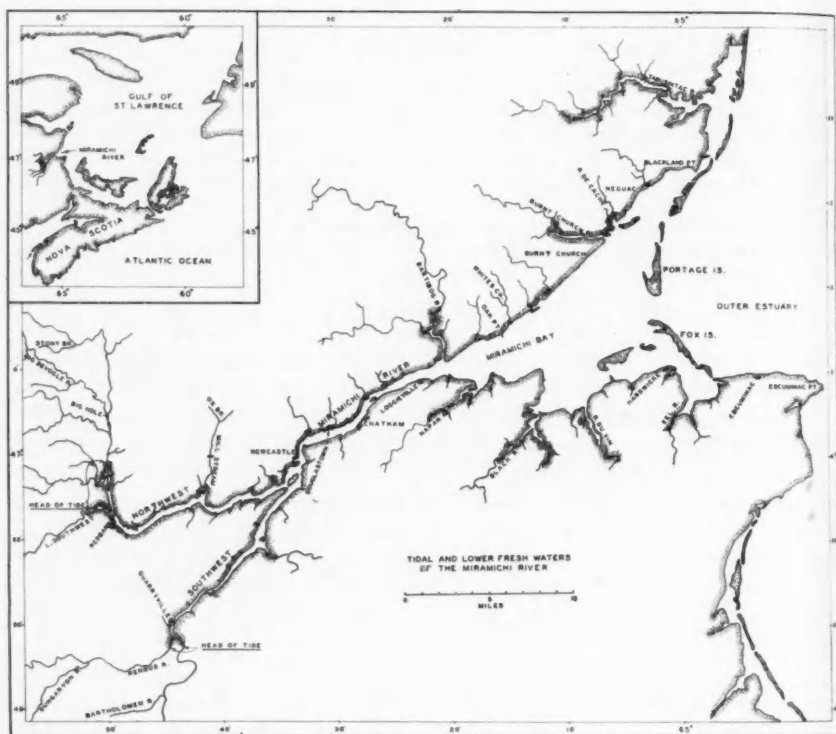


FIG. 1. The lower waters of the Miramichi River system.

While the maximum vertical tidal range is close to 5 feet, the average is about 2.5. During a complete tidal cycle in the summer, the average water exchange with the Gulf of St. Lawrence is approximately 15% (Bousfield, 1955).

Water temperatures and salinities at three points in the tidal part of Miramichi River and Bay are shown in Appendices I to VI. Temperatures and salinities at Newcastle for the years 1952 to 1956 inclusive are listed in Appendices I and IV respectively, at Gordon Point wharf opposite Loggieville for the years 1954 to 1956 in Appendices II and V and at Burnt Church for the years 1954 to 1956 in Appendices III and VI. These were recorded at approximately fortnightly intervals.

Similar recording has been continued by the Atlantic salmon investigation of the Fisheries Research Board.

Temperatures range from as low as -1.6°C in winter to as high as 25°C in midsummer. Salinities range from 0‰ to as high as 30‰ in midwinter some years. At Burnt Church, on the north side of the Bay, for instance, on August 15, 1956, the water temperature at the outer end of the wharf in 10 feet of water was 18.2°C at bottom and 18.3°C at the surface. The salinity was 27‰. On January 1, 1957, the temperatures at the same location were -1.6°C and -1.5°C , while the salinity was 30‰. At Newcastle, half way up the tidal part of the river, the temperature in the channel on July 15, 1956, was 18.8°C at bottom (38 feet) and 20.6°C at the surface. The salinities were 15‰ and 6‰ respectively. On January 2, 1957, the temperatures at the same location were -0.7°C and -0.1°C , while the salinities were 12‰ and 3‰ respectively. In the fresh waters of the River, the temperatures in summer range from cold spring water at the heads of the brooks to 25°C to 30°C in the lower sections. On July 10, 1955, for instance, the temperature reached 30°C at the salmon counting fence at Curventon, 4 to 5 miles above the head of tide on the Northwest Miramichi. For 3 to 5 months each year the Bay, River, and tributaries are ice-covered, sometimes to a depth of 3 feet in the Bay and lower River.

THE FISHERIES

The lobster fishery is conducted with traps in Miramichi Bay (inner estuary) and the outer estuary from May 1 to June 30. The smelt fishery is prosecuted in open water during November, but chiefly through the ice in December, January and February. It is carried on with bag-nets, set to fish with the current, and various types of box-nets which usually fish across the current. Bag-nets are fished chiefly in the River up to Newcastle. Box-nets are fished in the Bay and with suitable ice, often immediately outside of the islands across the mouth of the Bay. The tomcod fishery occurs during the smelt season. Tomcod are caught chiefly in bag-nets in the main River and in the tidal sections of the larger tributaries to the Bay from November to January. The catch in November and December consists of "full" fish enroute to the spawning grounds. In January it is "spent" fish on the way down river. The oyster fishery during the autumn is carried on chiefly with rakes from open boats on both private and public beds in Miramichi Bay. Some drags are used in the deeper water. Gaspereau are caught in trap-nets set along shore in the upper part of the Bay and the River almost to the head of tide during the "up" spawning run in May and June. This run follows the peak of smelt spawning. The commercial salmon fishery is carried on from May to the last half of August as the fish come in from the sea and proceed up river. A large drift-net fishery is prosecuted within and off the outer estuary. A set-net fishery takes place in the upper part of Miramichi Bay and up river almost to the head of tide in the Northwest and Southwest branches. Herring are also taken in drift-nets in the spring in the outer part of the Bay and outer estuary. Some herring are also taken in August and September. Quahaugs

(*Venus mercenaria*) are raked from anchored boats in the outer part of the Bay during the warmer months, June to September. In the Neguac region of the Bay, bar clams are taken from June to September with rakes from drifting boats and at low tide with hoes. Soft-shell clams (*Mya arenaria*) are taken with forks and shovels in shallow water at the same time and place. The plaice fishery is almost entirely on the south side of the estuary off Escuminac. Small draggers account for most of the catch, though trap-nets take some along shore. A small quantity of cod is hand-lined during salmon drift-net operations.

THE FISHES

Though Halkett (1913) prepared a check list of the fishes of Canada and Newfoundland, and Perley (1852) wrote a report on the sea and river fisheries of New Brunswick as well as a descriptive catalogue of the fishes of New Brunswick and Nova Scotia, to date there has been no comprehensive account of the Miramichi fish fauna. However, records of some fishes in the Miramichi have been published by Cox (1893; 1896a, b; 1905), Lanman (1874a, b, c), McKenzie (1952, 1953), McKenzie and Scott (1956), and White (1953, 1957). Records of fishes in neighbouring areas have also been published by such investigators as Cox (1899) who made a survey of the freshwater fishes of the Gaspé region. Needler (1940) published a list of the fishes of Malpeque Bay, Prince Edward Island; Schmitt (1904) prepared a list of the fishes of Anticosti; Stafford (1912a, b) wrote of Malpeque Bay and Gaspé fauna; Cox (1921) of fishes collected in 1917 off Cape Breton and the Magdalen Islands, and Thompson (1932) reported on Newfoundland fishes. Various investigators mentioned in general the distribution of certain fishes in the Gulf of St. Lawrence—Clemens (1920) the mutton fish, Connelly (1920) the angler, Cox (1920) the lumpfish, and Huntsman (1918) the Canadian plaice.

While engaged in an investigation of the smelt of the Miramichi from 1941 to 1957, much information was accumulated on the other fishes of the area through experimental fishing for smelt and through the kindness of fishermen who permitted the examination of their catches or who brought in the rare fishes for identification. Freshwater species were obtained during smelt spawning surveys and during salmon investigations in the area.

Bigelow and Schroeder (1953) for the marine species and Scott (1958) for the freshwater species have in general been used as guides for the nomenclature in this account. Thirty-nine families represented by 78 species of fishes have been found in the waters of the Miramichi system.

Family *Petromyzonidae*
Petromyzon marinus Linnaeus

Lampreys
Sea lamprey

Frequently called lamper eel locally. Common throughout the estuary, main river, the main branches, and the larger tributaries. Its marks are frequently seen on salmon. The spawning run takes place the last half of June, when large numbers congregate below impassable falls and dams. At this time, males are distinguished

by a ridge along the back, while females have an enlarged fin behind the anus. In temperatures of 22 to 25°C, they have been seen attached to Mill Stream dam forming a row across the sloping face of the lower section, so numerous that their bodies touched. Handling did not frighten them and to free them from the dam they had to be "up-ended". The dam blocks their ascent of this stream.

Perley (1852) quoted Mr. J. L. Price of Ludlow on the Miramichi as having reported years ago that lampreys were found in all the main waters of the Miramichi and "frequently dead toward autumn". "Mr. Price (also) remarked one peculiarity of this fish which distinguishes it from all other minor fish—when disturbed at the spawning season, it will pursue the intruder, however formidable, with great spirit even beyond the bounds of the water."

Family *Isuridae*

Mackerel sharks

Lamna nasus (Bonnaterre)

Mackerel shark

There appears to be only one record of a definitely identified shark for the Miramichi and it is *Lamna nasus*. In a personal communication, Dr Miles Keenleyside of staff of the Fisheries Research Board's Biological Station, St. Andrews, N. B., reports that a specimen of the above species was taken in a drift net off Escuminac Point on August 8, 1957. The estimated length was 11 feet and weight 500 to 600 lb.

One or two sharks are reported each season and one fisherman claimed to have seen only "half a dozen in the last 25 years".

Perley (1852) wrote that "this fish (*Carcharias vulpes*—the thresher shark) is a great enemy of the small whales in the Gulf of St. Lawrence. In the Bay of Chaleur, and lower part of the River Saint Lawrence, it is often seen attacking whales which frequent those localities". In view of the foregoing, this species could be among those seen by Miramichi fishermen.

Family *Squalidae*

Spiny dogfishes

Squalus acanthias Linnaeus

Spiny dogfish

Abundant in the outer estuary. They are a nuisance to fishermen especially during the autumn herring netting season.

Perley (1852) reported that a dogfish, opened on August 25, 1849, had young "very nearly fully formed" and concluded that "The young fish are produced at the end of August or early in September". This is in agreement with the general opinion of the present day (1957) fishermen.

Family *Rajidae*

Skates

Raja erinacea Mitchill

Little skate

Common in the outer estuary where it grows to a length of about 2 feet. Occasionally larger specimens are found. Most of the characteristics of the skate in the Miramichi favour *erinacea* but are so different from those of this species in more southern localities that it might be considered a local race or even a

subspecies. Mr Wm. C. Schroeder of the Museum of Comparative Zoology, Cambridge, Mass., reports that the teeth and alar spine area (outer part of wings of maturing males) resemble *ocellata*.

Family *Acipenseridae*
Acipenser sturio Linnaeus

Sturgeons
Sea sturgeon

Usually called sturgeon and each year there are up to half a dozen reports of them being taken from May to December, chiefly in salmon and smelt traps in the main Miramichi River and the Northwest and Southwest branches to within 3 to 5 miles of the head of tide. However, in 1954 about 25 sturgeon were taken in 3 salmon traps at Burnt Church on the north side of Miramichi Bay during early summer. This was quite unusual, for sturgeon are rarely taken there. They range from 2 to 4 feet in length, with 27 pounds being the heaviest specimen seen. They are not wanted commercially—no markets being at hand, nor are they valued locally as food.

Family *Clupeidae*
Clupea harengus Linnaeus

Herrings
Herring

Very common in the outer estuary and in Miramichi Bay during the spring and summer, and up the River to within a few miles of the head of tide in autumns with little rain. Occasionally, as in late May and June 1941, "sardine" herring are taken in the spring and early summer in the tidal section of the River as far up as Chatham. Almost every autumn, there are also "sardine" herring in the River. Some years, e.g. early November 1956, the bag-nets set opposite Loggieville for smelt and tomcod caught more sardine-size herring than the desired species. Salinities where the net was set were 20–22‰. There is practically no market for them and piles have been left along the shore during the winter.

Perley (1852) reported that herring were very abundant along the eastern coast of New Brunswick where a spring run appeared towards the end of April or early in May and was taken with set-nets while spawning. These fish were thin and poor, and of little value as food but a run of fat fish in good condition appeared on the coast late in August. However, Perley pointed out that though valuable and abundant, the herring were taken chiefly by the settlers for their own use. The exports of salt herring (conversion factor of 300 lb fresh round weight to 1 barrel pickled) from the Miramichi during an 8-year period was as follows (weights in lb):

1841	1842	1843	1844	1845	1846	1847	1848
42,000	103,800	65,700	324,000	1,119,600	357,600	356,700	0

A commercial catch of adult sizes in 1953 of about 2,000,000 lb indicates an increase in the size of the herring fishery of this area compared to 100 years ago.

So much spawning occurs off Escuminac Point in the early summer that the water sometimes appears milky.

Pomolobus pseudoharengus (Wilson)

Alewife

Usually called gaspereau or just "spreau". Very common in the spring when they run up the main River and the larger tributaries to spawn in June. At this time smelt spawning is nearly completed. As they move upstream, many of them close to shore, groups of fish are often seen swimming rapidly anti-clockwise in a circle 3 to 6 feet wide. In a matter of seconds this so-called nuptial dance or swim ends in a big splash. During the spawning on the Northwest Miramichi, they are frequently so numerous on the rapids for some miles above the head of tide that it is difficult to wade about without treading on fish at every step.

Large quantities of eggs are found on these rapids in the Miramichi, though Bigelow and Schroeder (1953) report that in the Gulf of Maine area this species spawns in ponds and "sluggish stretches of streams, never in swift water

Spawning on the rapids at least 5 miles above the head of tide is contrary to Perley (1852) who wrote that "In the North West Miramichi, these fish ascend no higher than the deep pool at Red Bank". As Red Bank is below the head of tide, it means that these fish are going farther upriver to spawn nowadays (1957) than about 100 years ago.

After spawning, the gaspereau swim quite rapidly downstream in great schools, often travelling at the surface in the tidal part of the River. When they swim in a dense school just under a calm, smooth surface, their dorsal fins often break the surface, giving the impression of a breeze ruffling the water in patches. The whole school dives on approaching a bridge. This occurs at the point where the line between the superstructure of the bridge and the head of the school makes about a 45° angle with the surface. It is at about this angle that the bridge with its traffic would first come within the vision of the leading members of the school (Curtis, 1938).

J. T. Williston, Miramichi Post Office, stated (Perley, 1852) that in his opinion the spring fish taken in the river were thin and dry and not the same as the summer fish which were fatter, smaller, and more yellow in colour.

Gaspereau have been of considerable importance during certain years. For example, an average of 11,000,000 lb was taken annually with trap-nets in the early 1950's, while only about 200,000 lb was taken in 1939. Market fluctuations and export trade would seem to govern the size of the catch more than natural abundance nowadays. However, natural abundance rather than markets was apparently the controlling factor 100 years ago for Perley (1852) wrote that the deep pool at Red Bank "at times has been swept so thoroughly (with seines) that not a fish has been left, and the gaspereau fishery as such may be said to have ended in the North West". He also wrote that "The gaspereau fishery on the Miramichi was almost a total failure this past (1849) season".

Pomolobus aestivalis (Mitchill)

Blueback

Cox (1896b) listed both *Clupea vernalis* and *Clupea aestivalis* (now *Pomolobus pseudoharengus* and *Pomolobus aestivalis* respectively) as occurring in

Miramichi Bay, the latter running later than the former. However, no specimens in our collections have been positively identified as *P. aestivalis*.

Alosa sapidissima (Wilson)

Shad

Very common in the spring when they run with the gaspereau into fresh water to spawn. However, few, if any, are found in certain wide-open tributaries, whereas the gaspereau go into all of the larger ones.

In 1852, Perley wrote that "there is now no such fishery in the Miramichi, nothing being heard of shad". However, Perley also wrote that "The shad enters the Miramichi in the latter part of May, and remains until the middle of July; occasionally it ascends the South West as far as Boiestown, but the greatest numbers are found below the mouth of Eteinnes River, always resting in deep, quiet water". In contrast to this, trap-nets set along the shore at the head of the Bay and in the River now-a-days yield a commercial catch which has remained in the neighbourhood of 500,000 lb each year.

Family Salmonidae

Salmons

Salvelinus fontinalis (Mitchill)

Brook trout

Usually called speckled trout or just trout. Very common (as it was in Perley's time) in all the freshwater parts of the system where it provides sport fishing, such streams as Rivière de Cache, Bartibog, and Renous being particularly well known.

Some run to sea and are occasionally caught in the tidal parts of the Miramichi in May and June in trap-nets set for gaspereau.

Salmo salar Linnaeus

Salmon

William Davidson (Perley, 1852) established himself on the banks of the Miramichi as the first British settler in 1764 and for many years took 1400 to 1800 tierces (875,000 to 1,125,000 lb round fresh weight) of salmon annually. The quantities of salmon in those early days were reported to be "perfectly prodigious", and although many were still being taken about 1850, Perley wrote that "the supply diminishes from year to year". Pickled salmon (conversion factor of 300 lb fresh round weight to 1 barrel pickled) exported from the Miramichi (Perley 1852) over an eight year period were as follows (weights in lb):

1841	1842	1843	1844	1845	1846	1847	1848
484,200	688,500	327,900	484,800	650,800	43,800	459,300	471,300

About 1845 buildings were erected (from 1643 to 1647 there was an establishment here for taking walrus, chiefly) and a fish stand was located at the mouth of Miramichi Bay on the northeastern end of Portage or Waltham Island. During August of 1850 about 30 boats operated out of this station and in addition to other products about 22,000 lb of salmon were put up in hermetically sealed tins. The quantity taken in 1848 was greater than in any of the preceding 20 years

according to a letter from J. L. Price of Ludlow, N. B., reproduced by Perley. However, in spite of this, Perley (1852) concluded in respect to the Miramichi "that the salmon fishery has greatly decreased, and is in a fair way of being destroyed also".

Nowadays this species is still very common, making this River well known among the sport fishermen of the world. Between 1952 and 1955, about 35,000 fish were taken annually by angling. Another 30,000 were taken commercially in a drift-net (gill-net) fishery in the outer estuary and in set-nets in the tidal portion of the River. At 10 lb per fish, this would be 350,000 and 300,000 lb respectively.

The up-river run begins in May and continues until late October or early November when spawning occurs. Some of the spawning fish go upstream as far as physically possible, which is usually about 10 miles above Little Bald Mountain on the Northwest and 25 miles above Juniper on the Southwest Miramichi. Some of the fish return to sea after spawning in the autumn. Others winter in the fresh water going downstream during and just after the spring freshet. At this time, they are caught as "black salmon" by sport fishermen.

Investigations have shown that most of the young remain in the Miramichi 3 years, going to sea as smolts in late May and June. The grilse, as indicated by Perley (1852) are almost all males, which return the following summer, after 1 year at sea, while most of the females and some males return as "salmon", up to 13 lb in weight, after 2 years at sea.

Family Osmeridae	Smelt
<i>Mallotus villosus</i> (Muller)	Capelin

This fish is very rarely found in the Miramichi though it may possibly be the bluish-coloured fish that precedes the early summer run of cod off Escuminac. In Chaleur Bay, about 50 miles north of the Miramichi, capelin were formerly taken commercially, forming an integral part of the cod fishery (earliest bait) which "does not fairly commense until the arrival of the capelin" (Perley, 1852).

The Miramichi area appears to be close to the southern limit for this species on the west side of the Gulf of St. Lawrence. Occasional specimens have been caught at Chatham and Newcastle, though the species is not typically an anadromous fish.

<i>Osmerus mordax</i> (Mitchill)	Smelt
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Very common, supporting a winter commercial fishery averaging 1,500,00 lb in 1952 and 1953 valued at about \$250,000. This fishery is prosecuted with trap-nets, chiefly through the ice. The fish are frozen on the ice.

A hundred years ago, Perley (1852) wrote that smelt ascended the Miramichi and its tributaries "in almost miraculous quantities very early every year" but did not mention any fishery for them. However, in writing generally of the smelt in the Gulf of St. Lawrence, he did indicate that this great delicacy, often called "frost fish", was taken through the ice in winter when in the best condition and that "under proper management, this fishery, might be made one of considerable profit as the smelt is really delicious and always highly esteemed". It was not until

almost 25 years later, 1870 to 1875, that interest was taken commercially in the smelt in the Miramichi area (McKenzie, 1946) with the introduction of a primitive type of bag net having no trap in it. Many changes have taken place since then leading to the modern double-end box net used by the majority of smelt fishermen on the Miramichi to-day.

The spawning run reaches the head of tide late in April. Entrance into the various tributaries occurs when their water temperatures reach 6° to 7°C. The spawning smelt occupy from a few hundred yards to 9 or 10 miles in such branches and tributaries as the Southwest Miramichi and the Bartibog River. Spawning lasts for about 6 weeks, the spent fish spending the summer and autumn in the outer estuary. The eggs hatch in 2 to 3 weeks and the young are carried quickly out of fresh water into the tideway where they grow to maturity in the lower river and estuary in 2 years (McKenzie, 1958).

None of the lakes in the Miramichi system contain smelt populations which never go to sea. This is unlike Lake Utopia in southwestern New Brunswick where smelt do live without going to sea.

Family Catostomidae

Suckers

Catostomus commersoni (Lacépède)

White sucker

Abundant in the lakes and freshwater streams of the Miramichi.

In late May and early June, 1941, suckers were caught in box and bag nets set off Chatham. This is in the tidal part of the river but no records of salinities for this region or time are available. Some are also taken during the winter in the smelt nets off the larger tributaries along the southern part of Miramichi Bay, according to Mr Roy Lloyd of Escuminac.

In speaking of this fish, Mr J. L. Price of Ludlow (Perley, 1852) on the Southwest Miramichi stated that it was used as food "by many persons, usually fried while fresh but sometimes slightly salted and dried". Mr Price also stated that "its young are greedily devoured by the king-fishers; it is the chief prey of the fish-hawk, and it affords a desirable repast even to the dainty trout. Mr Price mentioned to the writer (Perley) that he once met with a trout of considerable size in the Miramichi which had been choked in an unsuccessful attempt to swallow a large sucker".

Family Cyprinidae

Minnows

Notemigonus crysoleucas (Mitchill)

Golden shiner

Rather common in the larger, lower, warm fresh waters of the Miramichi.

Semotilus atromaculatus (Mitchill)

Creek chub

Common throughout the fresh waters of the Miramichi, tending to be more abundant in the smaller streams and particularly so in the Renous.

Semotilus corporalis (Mitchill)

Fallfish

Abundant in all the larger fresh waters of the Miramichi. Its presence is indicated by pyramids of stones placed just out of the direct currents at spawning time in the early summer. These piles of stones are often 3 to 4 feet long per side at the base and 2 to 3 feet high.

Margariscus margarita nachtriebi (Cox)

Northern pearl dace

Rare; taken only in a small, spring-fed pool at the junction of the Northwest Miramichi and Big Sevogle in 1953 and 1954 by Mr H. C. White, though it probably occurs in other similar restricted habitats. Cox (1901) reported this species as occurring in Gaspé, Que., but not in New Brunswick; Livingstone (1953) found it in a number of locations in eastern Nova Scotia.

Chrosomus eos Cope

Northern redbelly dace

Rather rare except in restricted, warm, weedy areas of the fresh waters of the Miramichi. This species was first found in the Miramichi by Mr H. C. White (now retired from the Fisheries Research Board of Canada). Cox (1896a, b) reported it as occurring only in southern New Brunswick, while Livingstone (1953) found it in central and eastern Nova Scotia.

Pfille neogaea (Cope)

Finescale dace

Rare; taken only in one small, spring-fed pool at the junction of the Northwest Miramichi and Big Sevogle in 1953 and 1954 by Mr H. C. White. Cox (1896a, b) did not record this species from the Miramichi, though he found it in southern New Brunswick. White, too, found it in southern New Brunswick, particularly Loch Lomond. It is not known in Nova Scotia.

Couesius plumbeus (Agassiz)

Lake chub

Common throughout all accessible parts of the freshwater streams in the Miramichi watershed.

Rhinichthys atratulus (Hermann)

Blacknose dace

Common throughout all accessible parts of the freshwater tributaries of the Miramichi system, even into the smallest springwater brooks where their only associates are the speckled or brook trout and the freshwater sculpin. May occasionally be taken in the brackish water at the mouths of the tributaries to the Miramichi below the head of tide.

Cox (1905) indicated that *atratus* and *cataractae*, appear to intergrade at times for he found occasional specimens of *atratus* with long noses like *cataractae*. White also found similar specimens but these have been lost. White and the author were unable to find any during a trip for this purpose in May 1957 to Ox Brook on the Chaplin Island road where White had taken a specimen some years earlier.

Family *Notropis cornutus* (Mitchill)

Common shiner

Common in all the lower, warmer fresh waters of the Miramichi system.

Family *Ictaluridae*

Catfishes

Ictalurus nebulosus (LeSueur)

Brown bullhead

Not uncommon in lakes, ponds and deep holes in streams in the Miramichi watershed. It is occasionally found in brackish water; for example, a specimen of 17.1 cm total length was taken in a smelt bag-net January 10, 1946, fishing in 40 feet of water off Chatham in the main Miramichi River. The salinity at this depth in the River in mid January usually varies from 8 to 15 parts per thousand.

Family *Anguillidae*

Eels

Anguilla rostrata (LeSueur)

Eel

Very common, often found in salmon trap-nets. As much as 15,000 lb are taken commercially some years on the north side of Miramichi Bay and in the Northwest and Southwest Rivers in eel traps of various designs. Years ago Perley (1852) reported that there were in the Miramichi, great quantities of eels which were taken chiefly through the ice in winter with spears.

Family *Poeciliidae*

Killifishes

Fundulus diaphanus (LeSueur)

Banded killifish

Taken commonly in the shallow weedy areas of the fresh waters of the system.

Fundulus heteroclitus (Linnaeus)

Common mummichog

Sometimes called chub locally. Common in the tidal parts of the Miramichi system and occasionally taken in the freshwater parts.

Family *Scomberesocidae*

Needlefishes

Scomberesox saurus (Walbaum)

Needlefish

Rare; only a single specimen came to hand from 1941 to 1957. This was a partly decayed individual, 11½ inches long, found on shore at Whites Creek on the north side of Miramichi Bay by Mr Donald Ross, November 10, 1947. Cox (1896a) too, reported only one taken, a 9-inch specimen along the north side of Miramichi Bay. Three specimens were identified in the Prince Edward Island area in 1931 and none were reported from the Trois Pistoles region of the St. Lawrence River (Préfontaine, 1933; Vladykov and Tremblay, 1935). The Miramichi is thus close to the northern limit of the range for this species in the western Gulf of St. Lawrence, though Thompson (1932) found it at a number of points around Newfoundland.

Family *Merlucciidae*

Silver hake

Merluccius bilinearis (Mitchill)

Silver hake

Rare; considered as a "stray" in the Gulf of St. Lawrence. The only specimen seen was 17.0 cm long, caught in a smelt net on December 24, 1954, in the upper part of Miramichi Bay (McKenzie and Scott, 1956).

Family *Gadidae*

Cods

Boreogadus saida (Lepechin)

Arctic cod

Four specimens of this typically northern species were found in Miramichi Bay in temperatures of -1.5°C during the smelt fishery of 1950-51 (McKenzie, 1953), these being the most southerly known. Vladikov (1945) has recorded this species along the north shore of the Gulf of St. Lawrence.

Gadus callarias Linnaeus

Cod

Common in the outer estuary of the Miramichi where the annual catch varies from 100,000 to 1,500,000 lb valued at \$2,500 to \$35,000.

Perley (1852) stated that "near the shores of New Brunswick (in the Gulf of St. Lawrence) the best fishing grounds, or rather those most frequented, are from Point Escuminac to Miscou. . . .". The exports of dried cod (conversion factor of 336 lb fresh round weight to 1 quintal dried) from 1842 to 1848 from the Miramichi were as follows in lb.

1842	1843	1844	1845	1846	1847	1848
163,296	100,800	50,400	23,520	91,392	469,728	100,128

Because of the rare advantages this coast offered for its development, Perley urged the expansion of this fishery. During the last 100 years, there has been some expansion and the dried cod production of the early days has been replaced to quite an extent by the production of fresh or rapidly frozen cod fillets.

A "run" of cod inshore in June along the south shore of the outer estuary, when they follow schools of small unidentified bluish-coloured fish (possibly capelin), brings some into the traps there for a few days but most of the cod are taken by hand-line while drift-netting salmon.

Microgadus tomcod (Walbaum)

Tomcod

Very common. This species is taken during the winter smelt fishing season in the main Miramichi River and upper part of the Bay. From 500,000 to 1,000,000 lb valued at about \$20,000 are taken annually.

The spawning run into the lower freshwater parts of the main branches takes place during the last half of November and early December, with the return movement reaching a peak the last half of January. When the commercial fishing season includes the month of November instead of beginning on December 1st, the "up" run of "full" fish is exploited as well as the "down" run of "spent" fish in January.

Gadus ogac Richardson

Greenland cod

The first two specimens of this typically northern species identified in Miramichi Bay were taken in March, 1949 (McKenzie, 1952). A continued search after this time showed that this species is not uncommonly caught in the Miramichi during the winter smelt season. Nor is it a newcomer; fishermen report taking as many as 99 on one occasion from a smelt net off Escuminac in 1934 or 1935. Most years they are much scarcer, but in the 1956-57 smelt season they were again fairly numerous, 73 being taken in a net off Escuminac on one occasion.

This fish, known as *pilote* to French-speaking fishermen, is sometimes found on the cod fishing grounds in the deeper waters of the outer estuary during the summer. They are of no importance as the flesh is not esteemed as food.

This species does occur somewhat farther south—Bras d'Or Lake, Nova Scotia, where it is considered a small but permanent part of the fauna (Scott, 1952).

Melanogrammus aeglefinus (Linnaeus)

Haddock

Sometimes called haddie locally. Rare, being taken only infrequently during the summer in the outermost part of the estuary. While haddock are taken in small quantities off the northeastern coast of New Brunswick and the outer end of the Gaspé peninsula (Needler, 1930) they do not come into the Miramichi in any numbers; not more than one fish per thousand pounds is taken in dragging operations. However, it is reported that 25 to 30 years ago this species was more abundant.

Pollachius virens (Linnaeus)

American pollock

This species is taken occasionally in the outer part of the Miramichi estuary in the salmon drift-nets. They are too scarce to be recorded in the fisheries statistics, although they appear to be increasing in numbers during recent years. This species has been reported north as far as the mouth of Chaleur Bay (Jean, 1954).

Perley (1852) did not see "in the Gulf of Saint Lawrence a single specimen of this fish" nor had "he ever met a fisherman who had taken one within the Gulf except near the northern end of the Strait of Canso". This means that during the 100 years between then and the present, this species has spread much farther north into the Gulf of St. Lawrence.

Urophycis tenuis (Mitchill)

White hake

In 1905 Cox said that "small specimens of this species are taken in smelt bag-nets in Miramichi Bay along with the closely allied form, the squirrel hake". However, all the specimens examined have been *U. chuss* with the larger scales, 100 to 110 rows, compared to about 140 rows of smaller scales found on *U. tenuis*.

Urophycis chuss (Walbaum)

Squirrel hake

Usually called ling or just hake. Common, being frequently caught in the autumn during the open-water fishing in November and December in the main

Miramichi River and Bay, especially in a dry year. In dry seasons the salinity is higher, apparently permitting them to move up to the vicinity of Newcastle.

Not used commercially other than with the trash fish.

Enchelyopus cimbrius (Linnaeus)

Four-bearded rockling

Rare; the only specimen seen was 18 cm long, caught in Miramichi River off Douglastown in a bag-net on November 14, 1954. This species was not reported for Malpeque Bay but a number of specimens were taken at Trois Pistoles in the St. Lawrence River.

Brosme brosme (Müller)

Cusk

Perley (1852) did not mention this species as occurring in the Gulf of St. Lawrence. However, Cox (1896b) indicated it as rare for the Miramichi and this agrees with the fishermen's reports for this region. A personal communication from Dr Y. Jean of the Fisheries Research Board of Canada staff indicates that it is also taken at rare intervals farther north in the mouth of Chaleur Bay.

Family Hippoglossidae

Halibuts

Hippoglossus hippoglossus (Linnaeus)

Atlantic halibut

Found in the outer estuary, though not frequently enough to be of economic importance, only about half a dozen per year, ranging in size from 60 to 75 cm long are taken in the whole region according to W. G. Irving of the Fisheries Research Board's salmon investigation.

Larger halibut were apparently taken years ago, for Perley (1852) stated that fishermen from Tabusintac operating well over towards Escuminac "frequently took halibut of large size, a single fish being sometimes sufficient to fill a barrel".

Hippoglossoides platessoides (Fabricius)

American dab

Known locally as plaice or dab. Rare; none were seen by the author. However, Huntsman (1918) indicated their distribution to include the deeper waters off the Miramichi and fishermen report that on rare occasions they catch one on line-trawl.

Family Pleuronectidae

Flounders

Limanda ferruginea (Storer)

Yellowtail flounder

Known also as rusty dab. Common in the outer estuary and beyond where it makes up 25 to 35% of the commercial catch of flatfishes during dragging operations.

Pseudopleuronectes americanus (Walbaum)

Winter flounder

Known locally as the redback flounder or lemon sole. Very common in the tidal part of Miramichi River and Bay (inner estuary) where they comprise about three-quarters of all flounders caught. In this part of the River system only the

smelt nets take flounders. Only a few of those caught in this way are large enough to use. In the outer estuary, they are larger, 30 to 45 cm in length and $\frac{3}{4}$ to 3 lb in weight; up to 10,000 to 14,000 lb may be taken per haul per trap-net late in May and June when these fish congregate on shore, feeding on herring spawn. At this season no other flounders are caught in these nets. Later these fish are taken offshore in the outer estuary and beyond with drags and comprise about 65 to 75% of the flounder catch.

Spawning occurs in late winter and early spring.

Liopsetta putnami (Gill)

Smooth flounder

Often called the blackback flounder locally. Common in the Bay (inner estuary) and tidal part of Miramichi River to above Newcastle (seined just above Newcastle, June 13, 1941) where they comprise 18 to 20% of the 3 species—sand, winter, and smooth flounders—caught in the smelt nets during the winter. They are, however, usually too small (rarely exceeding 20 cm) to be of much use. Later in the winter, even the large ones are of no use, being “spent”, thin, and watery.

Spawning takes place in late December and the first half of January in below zero Centigrade temperatures. At this time the males are almost as rough between the eyes as the winter flounder, even though the space is very narrow and in the form of a ridge.

Glyptocephalus cynoglossus (Linnaeus)

Witch flounder

Uncommon; possibly 2 or 3 per day are taken in dragging operations in the outer estuary.

Family *Bothidae*

Windowpanes

Lophopsetta maculata (Mitchill)

Sand flounder

Often called “windowpane” or “sunlight”, and occasionally “fluke”. Fairly common, but it has little or no economic importance. It is found in the inner estuary or Bay and tidal part of the River to above Newcastle (seined June 13, 1941, just above Newcastle) but is less common in the deeper waters of the outer estuary.

Family *Atherinidae*

Silversides

Menidia menidia (Linnaeus)

Silverside

Abundant throughout the tidal parts of the Miramichi during summer and autumn, where it is often mistaken for smelt. Usually only two sizes are found, the young of the year and a few of those apparently a year older; rarely exceeds 12 to 13 cm long.

In spite of being so abundant during the summer, none are ever taken in the smelt nets fished in the lower River and estuary, though smelt of a smaller size are frequently caught.

Family Gasterosteidae

Sticklebacks

Pungitius pungitius (Linnaeus)

Nine-spined stickleback

All sticklebacks are locally called pinfish—no distinction of species. This species is abundant in weedy protected areas of both fresh and brackish water regions of the Miramichi. In fresh water this species prefers acid to alkaline conditions.

Gasterosteus aculeatus Linnaeus

Three-spined stickleback

Fairly common throughout the tidal and freshwater parts of the Miramichi, where it spawns in June. This species prefers alkaline waters, apparently shunning acid waters.

Gasterosteus wheatlandi Putnam

Two-spined stickleback

Common throughout the tidal waters of the Miramichi.

Eucalia inconstans (Kirtland)

Brook stickleback

Rare; collected only in a small, cold, spring-fed backwater just above the Big Hole on the Northwest Miramichi by Mr H. C. White in 1953 and 1954. Many similar habitats have been searched for this species by Mr White, without success.

Apeltes quadracus (Mitchill)

Four-spined stickleback

Very common around the shores of the Miramichi estuary, in the brackish water only.

Family Syngnathidae

Pipefishes

Syngnathus fuscus Storer

Common pipefish

Rare; none being seen by or reported to the author. However, Cox (1905) reported a specimen, "*Siphostoma fuscum* (Storer) J. and G.", taken in a bag-net in Miramichi Bay in February, 1898.

Family Scombridae

Mackerels

Scomber scombrus Linnaeus

Mackerel

Abundant during the summer in the outer estuary where from 250,000 to 500,000 lb are taken annually ranging in length from 30 to 40 cm. Young mackerel are often found in the Bay and lower parts of the main Miramichi River.

Years ago, Perley (1852) pointed out that in spite of the tremendous numbers of mackerel present in and off the Miramichi practically no one fished them. To emphasize this, he stated that in 1849, 20 to 30 United States vessels fished inside Miramichi Bay and obtained full fares of \$3 mackerel. He also mentioned that "the waters were perfectly alive with mackerel every season from

July 15 to September 15 yet there was no mackerel fishing". Even though the water was "boiling" with them none were taken. At still another point, he stated that in 1848 American vessels caught so many so fast off Escuminac that they had to engage men from shore at "high wages" to help clean and salt them. The small present-day Canadian fishery has thus developed from one that was "practically non-existent" 100 years ago.

Sarda sarda (Bloch)

Common bonito

Not uncommon, being about 25 to 35 cm in length and taken in the commercial mackerel catch. Up to 8 to 10 per catch are sometimes found among mackerel landed at Escuminac in the outer Miramichi estuary, according to Mr W. G. Irving.

Thunnus thynnus (Linnaeus)

Tuna

Rare; an occasional specimen is taken in the outer Miramichi estuary in certain years. One was reported in 1956, but none in the 3 years previous.

Family Xiphiidae

Swordfishes

Xiphias gladius Linnaeus

Swordfish

Rare; this summer visitor to the Gulf of St. Lawrence is uncommon in the waters of the outer Miramichi, but occasionally does become tangled in the salmon and mackerel drift-nets.

Family Stromateidae

Butterfishes

Poronotus triacanthus (Peck)

Butterfish

Known also as dollarfish locally. A not uncommon visitor in the waters of the Miramichi estuary and Bay. They were rare until the early 1950's but by 1954 were frequently taken in the salmon drift-nets. Numbers were still present and taken in the smelt nets in the lower Miramichi River and Bay during the autumn and early winter of 1954. This species has been reported from Malpeque Bay, Prince Edward Island, but not from the St Lawrence River or off Gaspé. The Miramichi is thus close to the northern limit of this species in the western Gulf of St. Lawrence.

Family Serranidae

Sea basses

Roccus saxatilis (Walbaum)

Striped bass

A hundred years ago, Perley (1852) indicated that "basse" was one of the principal fisheries of the Miramichi but that it had diminished greatly of late years. "Formerly great quantities of basse, some of very large size, were taken in the Miramichi but this fishery has also nearly ceased". The fishery was carried on by sweeping a large, long-handle dip-net around and around by walking around a large hole cut in the ice with the upper end of the handle across the chest. The

fish were said to be in a half torpid state, very stupid and easily taken as they would not stir. "This was done at night—the darker the night the better." The mesh of the nets had been reduced from four inches until when Perley wrote "the size has been diminished as the fish decreased in numbers, and now the very smallest are taken. Last winter (1848-49), great quantities of small basse were thus caught in the Miramichi, by very fine nets; and it is supposed that they are now nearly exterminated".

However, Cox (1893) indicating that this species was "exceedingly prolific" and "eminently fitted to perpetuate itself" stated that "in a few months of the winter of 1884 the estuary of the Northwest Miramichi alone yielded 94,000 pounds . . .". Nevertheless, the catch declined "until in 1889 it was only 2,000 pounds". This decline was attributed to overfishing and destruction of young fry and when "this was stopped and the taking of bass prohibited for three years these waters were soon restocked".

With such irregularities in the catch, this species continued to be taken commercially on the Miramichi up to about 25 years ago, fish up to 35 lb being taken frequently. However, large bass have been extremely scarce for some years now and a closed season on this species has been in force for about 25 years.

Many young bass 7 to 14 cm long are usually found in recent years (1945+) among the tomcod caught during the late autumn and early winter. These are of no use commercially.

Some years, quantities of bass 25 to 35 cm long are found in the spring and early summer during the gaspereau and shad spawning season.

Morone americana (Gmelin)

White perch

Rare; only a very occasional specimen is found during the shad and gaspereau fishery in the spring and early summer. Such specimens are 25 to 40 cm long.

Occasionally, also, a small specimen 8 to 15 cm long is found along with small bass of similar size during the tomcod fishery in the early winter.

Family Percidae

Perches

Perca flavescens (Mitchill)

Yellow perch

Rather uncommon in the freshwater parts of the Miramichi. Occasionally they are also found in the brackish part of the River being taken during the shad and gaspereau fishery in the early summer. One such specimen 32 cm long and 14 oz in weight was caught a mile above Newcastle in the Southwest Miramichi, June 9, 1950.

Family Cottidae

Sculpins

Cottus bairdi Girard

Mottled sculpin

Cox (1896a) reported this species under the name of *Uranidea Richardsoni* as occurring in Mill Cove Stream on the Miramichi near Newcastle in April 1892. However, no specimens in our collections have been positively identified as this species.

Cottus cognatus Richardson

Slimy sculpin

Known also as miller's thumb or just sculpin. Rare; reported only from the Stony Brook region of the Northwest Miramichi and the Bartholomew, a tributary of the Southwest Miramichi by Mr H. C. White (1953, 1957). It is confined as a rule to small, cold, spring-water streams where it associates with brook trout.

Myoxocephalus aeneus (Mitchill)

Grubby

This sculpin, called *greybird* by some fishermen locally, is abundant throughout the shoaler tidal parts of the Miramichi. It is frequently taken in smelt nets during the winter.

Myoxocephalus scorpius (Linnaeus)

Shorthorn sculpin

Not uncommon in the outer tidal waters of the Miramichi. While Cox (1896b) indicated that "typical" *scorpius* were found in Miramichi Bay, the species description given by Bigelow and Schroeder (1953) does not quite fit all specimens in this more northern latitude.

Myoxocephalus octodecimspinosus (Mitchill)

Longhorn sculpin

Abundant around ledges in the outer estuary.

Gymnocanthus tricuspis (Reinhardt)

Staghorn sculpin

Rare; the only specimen of this northern species found was 6.2 cm long, taken in the Miramichi at Bushville in July 1942.

Family Hemitripterae

Sea Ravens

Hemitripterus americanus (Gmelin)

Sea raven

Commonly called puffybelly or henfish and caught in the outer estuary where fishermen report taking 50 to 75 lb per day in dragging operations.

Family Agonidae

Alligatorfishes

Aspidophoroides monopterygius (Bloch)

Alligatorfish

Rare; the only specimen seen was 10.5 cm long, caught in a smelt net February 10, 1942, in Miramichi Bay. Cox (1905) also reported a 5¼-inch specimen taken in February 1898 in Miramichi Bay.

Family Cyclopteridae

Lumpfishes

Cyclopterus lumpus Linnaeus

Lumpfish

This species, sometimes called catfish, henfish or poule de mer, is common in the tidal waters of the Miramichi. During May and June up to 150 to 200 lb per trap are taken along the southern shore of the outer estuary. About 90% of these are green in colour, 10% are red, and an occasional one blue. One of the

largest seen, 46 cm long, was taken in a smelt fishing bag-net on December 27, 1950, at the ferry wharf in Chatham by Messrs Gorman and Landry.

Family **Liparidae**

Sea snails

Neoliparis atlanticus Jordan and Evermann

Sea snail

This tiny fish is found frequently among the smelt catches on the Miramichi throughout the winter. During the spring and summer it is occasionally found on the lobster traps.

Family **Labridae**

Cunners

Tautogolabrus adspersus (Walbaum)

Cunner

Called "blue perch" by many, this species is common throughout the tidal parts of the Miramichi.

Family **Ammodytidae**

Sand launces

Ammodytes americanus De Kay

Sand launce

Commonly taken in seining off sandy shores around Miramichi Bay and sometimes seen in large schools around the wharves.

Family **Pholidae**

Rock eel

Pholis gunnellus (Linnaeus)

Rock eel

Not uncommon in the tidal waters throughout the whole region. It is found in the smelt catches occasionally.

Family **Stichaeidae**

Blennies

Ulvaria subbifurcata (Storer)

Radiated shanny

Rare; the only specimen was 12 cm long, caught December 19, 1941, in the lower part of the main Miramichi River.

This species was not listed from Malpeque Bay, Prince Edward Island, but it was reported from Gaspé.

Family **Cryptacanthodidae**

Wrymouths

Cryptacanthodes maculatus Storer

Wrymouth

Rare; one specimen 50 cm long was caught at Hardwicke on the south side of Miramichi Bay on January 15, 1952.

This species has not been reported from either Malpeque Bay or the St. Lawrence River.

Family **Zoarcidae**

Ocean pouts

Macrozoarces americanus (Bloch and Schneider)

Ocean pout

Frequently called eelpout. Rather common, specimens of all sizes are regularly taken in Miramichi Bay and the outer estuary.

Family **Lophiidae**

Anglers

Lophius americanus Cuvier and Valenciennes

American goosefish

Sometimes called angler or big mouth. Rare; 1 or 2 specimens only were seen during September each year in the outer estuary, up to 2½ or 3 feet in length.

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APPENDIX I. Temperatures at Newcastle bridge, taken at half ebb tide; in degrees Centigrade.

	January	February	March	April	May	June	July	August	September	October	November	Dec.												
1952	2	17	1	9	1	18	1	15	6	16	2	16	1	14	1	18	3	16	2	17	1	17	1	17
Surface	0.1	0.0	0.0	0.0	-0.5	-0.1	0.1	0.1	7.8	6.8	15.8	16.1	19.2	24.5	22.2	21.4	19.8	16.0	15.3	10.7	5.3	2.0	0.7	0.2
Bottom	0.1	-0.3	0.1	-0.7	-1.0	-0.3	0.2	0.1	7.2	7.0	10.9	13.1	16.7	22.6	20.4	21.2	19.8	16.2	15.2	11.3	5.5	2.3	1.2	0.1
1953	1	17	1	14	1	16	1	15	1	15	3	16	2	15	1	15	1	15	1	15	4	16	1	15
Surface	-0.2	-0.2	0.0	0.0	0.0	-0.3	0.1	1.5	5.8	8.4	12.0	15.9	21.0	21.2	21.0	...	21.2	17.1	14.5	8.5	6.2	3.6	4.2	1.1
Bottom	-0.5	-0.4	-0.4	-0.1	-0.5	-0.4	0.1	1.7	5.8	8.5	12.1	15.9	20.4	21.0	21.0	...	19.6	17.8	14.4	8.8	7.8	4.4	6.9	1.5
1954	6	19	3	17	4	18	6	21	4	15	1	14	1	13	1	14	1	15	1	14	1	13	2	15
Surface	-0.2	-0.1	-0.3	-0.1	0.1	0.0	0.0	1.9	7.0	8.5	12.0	15.5	15.7	17.9	19.9	15.2	17.9	12.0	11.7	9.1	4.0	0.9	0.5	0.0
Bottom	-0.3	-0.3	-0.4	-0.3	-0.1	-0.2	-0.2	2.6	7.0	8.5	11.9	14.8	15.2	17.6	19.5	15.2	17.6	12.0	12.4	9.3	4.1	0.9	0.5	0.0
1955	1	15	4	15	2	14	1	16	1	20	1	16	2	15	1	15	1	15	1	15	1	15	2	15
Surface	0.1	0.0	-0.1	0.0	0.0	0.1	0.1	0.2	6.3	8.0	11.5	16.2	20.8	22.9	22.7	21.7	18.9	15.5	12.5	11.0	7.6	5.7	-0.7	-0.5
Bottom	-0.3	-0.3	-0.7	-0.3	-0.3	-0.5	-0.3	0.1	6.3	8.1	11.2	12.9	16.8	22.8	20.9	21.7	18.8	15.6	12.4	11.0	7.6	4.0	-0.7	-0.7
1956	1	17	1	14	1	15	3	17	1	15	1	18	2	16	1	15	3	17	2	15	1	17	3	17
Surface	-0.7	0.0	0.0	-0.2	-0.2	-0.3	-0.2	-0.2	4.6	6.1	11.0	17.9	18.1	20.6	?	?	17.9	15.6	11.6	9.8	7.2	2.9	0.0	0.0
Bottom	-0.7	0.0	0.0	-0.4	-0.4	-0.6	-0.7	-0.2	4.6	6.1	8.0	17.8	14.1	18.8	?	?	17.9	15.8	11.6	9.3	7.4	3.3	0.4	0.0

APPENDIX II. Temperatures at Gordon Point wharf, sampled at half ebb tide; in degrees Centigrade.

	January	February	March	April	May	June	July	August	September	October	November	Dec.														
1954			8	19	5	20	3	17	1	16	1	15	1	14	1	15	1	14								
Surface	...	...	...	0.1	-0.2	-0.5	1.5	7.3	10.1	11.5	14.9	16.9	17.6	14.1	17.1	16.9	13.3	12.3	9.2	6.0	1.8	1.1	-0.2	
Bottom	...	...	...	0.0	-0.3	-0.5	1.7	7.3	8.1	10.7	14.4	16.4	17.5	18.6	17.1	16.8	13.3	12.3	9.2	5.6	2.5	2.3	0.0	
1955			1	14	1	15	1	15	1	16	1	15	1	14	1	16	1	16	3	17	2	16	1	16		
Surface	-0.2	0.0	-0.3	-0.5	0.0	0.0	0.0	0.5	7.8	8.3	10.9	16.9	20.3	23.0	19.6	22.0	18.6	14.2	12.1	9.9	7.3	4.5	-0.6	-1.1		
Bottom	-0.7	-0.5	-0.8	-0.7	-0.4	-0.5	-0.7	-0.8	7.8	7.8	10.9	17.0	15.6	22.0	19.5	21.6	18.5	14.2	11.6	9.8	7.3	4.5	-0.7	-1.1		
1956			1	16	1	15	1	16	2	16	1	15	1	15	2	14	1	15	3	17	1	14	2	15	3	15
Surface	-1.0	0.0	-0.2	-0.5	-0.6	-0.8	-0.2	0.0	4.1	7.5	11.1	13.5	17.8	19.5	19.8	20.4	17.3	15.0	11.6	9.6	7.5	3.5	-0.2	-0.3		
Bottom	-1.2	-0.4	-0.2	-0.7	-0.6	-0.9	-0.9	-0.2	2.9	6.3	7.8	11.5	13.5	18.1	17.7	19.2	17.3	15.1	11.6	8.6	7.6	3.5	0.7	-0.5		

APPENDIX III. Temperatures at Burnt Church wharf, sampled at half ebb tide; in degrees Centigrade.

	January	February	March	April	May	June	July	August	September	October	November	Dec.														
1954			8	19	5	20	3	17	1	16	1	15	1	14	1	15	1	14								
Surface	...	...	...	-0.4	-0.2	-1.2	1.3	5.8	7.6	8.8	16.0	17.3	16.5	18.5	17.4	17.0	14.5	11.4	9.8	6.9	2.7	1.9	-1.1	
Bottom	...	...	...	-1.0	-1.0	-1.2	1.8	5.7	6.3	8.7	14.5	16.5	16.8	17.5	17.0	17.0	14.3	11.3	10.0	7.1	2.7	1.7	-1.0	
1955			1	14	1	15	1	15	1	16	1	15	1	14	1	16	1	16	3	17	2	16	1	16		
Surface	-1.2	-1.2	-1.3	-1.0	-0.5	0.0	0.0	1.8	8.0	9.6	10.1	14.8	17.8	20.9	20.2	20.1	18.0	12.5	11.7	9.4	7.2	4.6	0.7	-1.3		
Bottom	-1.3	-1.2	-1.3	-1.0	-1.0	-0.7	1.8	7.8	8.2	10.0	14.3	17.6	20.6	20.2	20.1	18.0	12.5	11.8	9.4	7.3	4.6	0.7	-1.3			
1956			1	16	1	15	1	16	2	16	1	15	1	15	2	14	1	15	3	17	1	14	2	15	3	15
Surface	-1.5	-0.4	-0.5	-0.7	-1.2	-1.1	-1.1	-1.3	2.9	4.8	10.7	16.4	15.5	17.6	18.0	18.3	16.8	14.2	11.6	9.0	7.4	3.4	-0.2	-1.1		
Bottom	-1.5	-1.0	-1.2	-1.0	-1.5	-1.3	-1.2	-1.3	1.9	4.9	9.1	13.1	14.5	17.6	17.3	18.2	16.8	14.2	11.7	8.3	7.6	3.1	0.5	-1.2		

APPENDIX IV. Salinities at Newcastle bridge, taken at half ebb tide; in parts per thousand.

	January	February	March	April	May	June	July	August	September	October	November	December
1952			18	15	6	16	2	16	1	14	1	17
Surface	...	...	2.2	...	0.8	0.5	0.7	0.6	1.9	2.6	2.7	8.6
10 feet	...	...	2.2	...	0.8	0.7	0.9	0.8	2.2	2.7	2.8	9.0
20 feet	...	...	4.2	...	1.0	0.7	0.9	0.9	3.4	3.1	3.2	11.7
30 feet	...	...	...	...	1.0	0.7	0.9	1.8	6.9	5.8	4.4	13.7
38 feet	...	...	...	...	1.0	0.9	0.9	3.9	7.4	7.1	6.5	16.1
1953	1	17	1	14	1	16	1	15	1	15	1	15
Surface	7.4	7.8	3.7	1.4	3.1	7.8	0.9	0.6	0.8	1.6	1.8	10.0
10 feet	8.4	8.1	4.0	1.4	3.7	8.1	1.1	0.6	0.9	0.6	1.7	10.0
20 feet	9.8	8.7	8.6	2.6	6.2	8.3	1.1	0.7	0.9	0.7	1.7	10.1
30 feet	10.2	9.1	10.9	3.1	9.6	10.2	1.1	2.0	1.0	0.7	1.7	10.1
38 feet	...	...	...	...	...	...	...	2.0	1.2	0.8	1.9	10.2
1954	6	19	3	17	4	18	6	21	4	15	1	14
Surface	4.4	4.0	7.8	3.3	0.9	2.7	3.1	0.5	0.5	0.5	0.9	1.4
10 feet	5.9	4.1	8.0	4.0	0.9	2.7	3.2	0.6	0.5	0.6	0.9	1.6
20 feet	6.9	4.9	9.1	7.4	1.2	3.9	3.5	0.7	0.6	0.6	0.9	1.7
30 feet	10.4	7.0	12.3	9.5	2.7	5.3	4.5	0.7	0.6	0.7	0.9	1.8
38 feet	...	...	...	...	...	...	...	0.8	0.6	0.8	1.0	1.8
1955	1	15	4	15	2	14	1	16	1	20	1	16
Surface	1.3	2.3	5.1	1.3	1.5	1.0	1.2	0.1	0.2	0.4	0.4	1.3
10 feet	1.3	2.4	5.4	1.7	1.5	1.1	1.3	0.3	0.3	0.5	0.4	1.3
20 feet	2.5	3.7	11.2	4.0	5.3	?	1.4	0.5	0.4	0.5	0.6	1.3
30 feet	8.4	9.2	18.0	5.3	10.8	9.9	8.6	0.5	0.5	0.5	0.6	3.2
38 feet	11.2	14.0	...	...	...	...	...	...	0.5	0.7	0.6	0.7
1956	1	17	1	14	1	15	3	17	1	15	1	18
Surface	15.7	0.6	1.1	4.9	4.5	7.7	4.6	0.4	0.5	0.3	0.4	1.3
10 feet	15.9	0.6	1.7	5.1	4.8	8.3	6.0	0.5	0.5	0.3	0.5	1.4
20 feet	16.2	0.7	2.5	6.6	6.2	9.5	8.2	0.6	0.6	0.4	0.6	1.5
30 feet	17.0	0.7	3.4	11.1	8.1	12.9	18.2	0.8	0.6	0.5	0.8	1.5
38 feet	...	...	...	...	...	...	...	...	0.8	0.6	0.5	1.3

APPENDIX V. Salinities at Gordon Point wharf, sampled at half ebb tide; in parts per thousand.

APPENDIX V. Salinities at Gordon Point wharf, sampled at half ebb tide; in parts per thousand.																										
	January	February	March	April	May	June	July	August	September	October	November	Dec.														
1954			8	19	5	20	3	17	1	16	1	15	1	14	1	15	1	14								
Surface	...	...	...	2.5	6.6	11.5	0.6	2.0	3.3	10.6	7.9	9.9	18.7	15.1	8.3	14.5	3.9	10.5	4.7	2.2	7.8	7.3	8.2	
10 feet	...	...	...	2.5	7.0	11.5	0.8	2.2	4.9	10.8	8.0	10.4	19.2	15.1	8.3	14.6	4.0	10.6	4.7	2.6	8.4	7.9	12.9	
16 feet	...	...	...	2.6	7.1	11.6	0.8	2.2	5.8	11.2	9.1	12.8	19.2	17.1	8.8	14.7	4.3	14.2	4.7	4.9	12.0	13.2	17.0	
1955			1	14	1	15	1	15	1	16	1	15	1	14	1	16	1	16	3	17	2	16	1	16		
Surface	6.5	3.9	10.1	7.3	1.8	2.4	3.1	1.1	0.3	1.7	1.4	2.8	12.5	12.4	15.8	16.5	17.4	21.7	22.1	20.5	22.0	20.3	24.1	23.8		
10 feet	6.7	6.4	11.1	12.4	1.9	2.7	3.2	1.2	0.4	1.9	1.5	2.8	12.5	12.5	15.9	16.6	17.5	21.8	22.1	20.7	22.0	20.4	24.7	24.2		
16 feet	11.5	15.7	15.0	15.3	13.6	12.5	17.8	18.0	0.7	3.0	1.5	9.1	18.0	15.7	18.0	17.9	17.9	21.8	22.1	20.8	22.1	20.5	24.9	24.3		
1956			1	16	1	15	1	16	2	16	1	15	1	15	2	14	1	15	3	17	1	14	2	15	3	15
Surface	22.2	1.5	6.9	12.0	12.4	18.8	9.2	3.4	3.2	3.0	1.4	4.3	10.9	10.0	13.3	15.0	20.1	21.8	21.2	13.6	22.4	20.7	12.5	9.3		
10 feet	22.4	1.6	7.1	12.5	12.4	19.4	9.5	3.5	3.2	3.1	1.4	6.5	16.1	10.4	15.9	15.1	20.4	21.8	21.5	15.9	22.6	20.7	13.8	14.6		
16 feet	22.9	19.0	7.4	13.8	12.8	20.4	17.3	9.2	11.6	5.7	13.6	14.2	21.7	17.1	20.5	22.2	20.5	22.0	21.7	22.0	22.6	20.8	19.5	20.0		

APPENDIX VI. Salinities at Burnt Church wharf, taken at half ebb tide; in parts per thousand.

	January	February	March	April	May	June	July	August	September	October	November	Dec.												
1954			8	19	5	20	3	17	1	16	1	15	1	16	1	15	1	14	1	15	1	14		
Surface	...	...	...	12.1	7.1	26.0	4.4	22.4	19.3	26.4	18.9	21.0	25.4	24.5	21.8	24.3	21.3	25.0	22.1	21.3	23.5	24.6	22.6	
9 feet	...	...	...	20.7	17.1	26.8	13.4	23.5	21.3	26.6	21.3	24.3	25.6	25.0	23.0	24.5	22.0	25.4	22.6	21.7	23.9	24.7	24.7	
1955			1	14	1	15	1	15	1	16	1	15	1	14	1	16	1	16	3	17	2	16	1	16
Surface	26.6	27.5	28.8	22.5	13.3	15.9	20.1	19.7	1.0	9.1	15.8	16.2	15.7	25.0	22.8	25.8	25.0	27.2	26.8	26.3	29.1	28.8	28.7	31.7
9 feet	26.8	27.7	29.1	25.9	19.0	20.5	24.3	21.7	2.4	17.5	16.1	16.3	25.7	25.0	23.2	25.9	25.5	27.4	27.2	26.3	29.2	30.1	31.2	31.9
1956			1	16	1	15	1	16	1	15	1	15	2	14	1	15	3	17	1	14	2	15	3	15
Surface	27.5	7.7	12.0	17.8	28.8	23.4	24.9	23.3	16.6	26.0	13.7	21.6	25.3	26.2	26.7	27.1	25.9	27.5	25.8	28.1	29.5	28.0	26.6	28.9
9 feet	30.3	24.5	23.7	24.1	29.9	28.3	28.8	24.7	22.5	26.0	19.0	23.2	25.7	26.3	26.7	27.1	26.0	27.6	26.2	28.3	29.6	28.3	27.4	29.5

Survival and Production of Pink and Chum Salmon in a Coastal Stream¹

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ABSTRACT

A study of the propagation of pink and chum salmon in the central coastal region of British Columbia was made for the years 1947 to 1956.

Timing, distribution and movement of the adults and fry are discussed. The effects of temperature, stream discharge, sex ratio and population density were considered in relation to survival of egg to fry. Within the limits observed, temperature, stream discharge and sex ratio were not affecting the population perceptibly, but population density was an important factor. The density of spawners in preceding years also affected the survival in subsequent years.

Predation was an important factor in keeping the fry output low: the number of fry consumed was approximately 500,000 during each migration.

Ocean survival, including the effect of fishing mortality, ranged from 5.2% down to 0.7% for pink salmon, and from 2.6% to 0.85% for chum salmon. Ocean survival for pink salmon before fishing mortality occurred ranged from 10.8% down to 1.0%.

Combination of freshwater and ocean survival rates indicate that a variation up to 190 times the lowest rate recorded is possible.

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INTRODUCTION

PURPOSE

THE FISHERIES RESEARCH BOARD of Canada began detailed studies at Hooknose Creek in 1947 in order to obtain information which would help in predicting and increasing the abundance of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon. (*O. keta*).

The survival and output of Pacific salmon from a given stream fluctuate considerably from year to year. Some of the many factors which produce variation in the survival and production of pink and chum salmon have been considered in this study.

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Pink and chum salmon have, to a very large extent, similar freshwater life histories. Factors which affect the survival and output of sea-going migrants of one species affect the other species in a very similar manner. The two species differ more in the marine phase of the life history and are treated separately for this stage.

POSITION AND DIMENSIONS OF HOOKNOSE CREEK

Hooknose Creek is in an area where a relatively large number of pink and chum salmon are caught each year. The location of the stream ($52^{\circ} 09' \text{ N. Lat.}$ and $127^{\circ} 48' \text{ W. Long.}$) is in Port John Bay on King Island in the north-central coastal area of British Columbia. The region is one of fairly heavy rainfall, ranging from 78 to 117 inches (198–297 cm) annually. Hooknose Creek is about 1.8 miles (2.9 km) long and drains from a small lake, Port John Lake, which is 1.65 miles (2.6 km) long. The watershed, though not extensive, drains mainly through the lake before entering Hooknose Creek. One tributary, however, runs directly off the mountains into the creek and during periods of heavy rainfall creates quick floods.

SPAWNING GRAVEL

Hooknose Creek averages 7 yards (6.4 m) wide and is about 1.8 miles (2.9 km) long and of this total area about 10,000 square yards (8361.3 sq m) are suitable spawning locations. The spawning beds are made up of stones from 5 inches down to $\frac{1}{2}$ inch (13 to 1.3 cm) in diameter, with liberal quantities of coarse sand intermixed. A certain amount of fine sand and silt is also present, but a general description of the spawning beds would be clean coarse gravel. Portions of the stream bed which are generally unsuitable for spawning include areas where the stream is narrow and the water is usually too deep and fast or where it forms large deep pools containing large alga-covered rocks. In addition there are areas at the edges of the stream where the water level may vary in height, exposing such regions to drying or freezing. These areas have been termed "fringe areas". In some years fringe-area spawnings show greater survival ratios than other spawning areas in the stream, but these are a consequence of relatively constant water levels and absence of persistent freezing temperatures.

STREAM DISCHARGE

Stream discharge figures from Hooknose Creek range from 10 cubic feet per second ($0.28 \text{ m}^3/\text{sec}$) in the middle of summer and in cold winter weather to as much as 600 cfs ($17 \text{ m}^3/\text{sec}$) in the spring and fall. The greatest discharge occurs in the fall. As indicated above, annual variations in the amount and character of the discharge may cause considerable variation in the availability and suitability of spawning grounds.

AIR AND WATER TEMPERATURES

Air temperatures of this north and central coastal region are generally moderate in their range, while water temperatures show relatively large differences

between maximum and minimum. Water temperatures at Hooknose Creek range from 14° C in the summer to as low as freezing for a short period in the winter. Ice has been recorded for the surface water of the stream and from the gravel of shallow fringe areas.

PINK SALMON

Mature pink salmon enter the stream from the sea in the fall when creek water temperatures range from 14° to 8° C. Most spawning occurs during the latter part of September and early October when mean water temperatures are about 12° C. This upstream migration from the sea, although basically actuated by inherent internal factors, is influenced in its timing by the water levels of the stream. The fish after entering the stream distribute themselves over the gravel bars where the female begins to scoop out a nest. The spawning behaviour of some other species of Pacific salmon has been amply described by several authors (Schultz and students, 1935; Shapovalov and Taft, 1954; Burner, 1951; and others). Spawning pink salmon select gravel of certain characteristics as to size, dirt, silt and water velocity and only under crowded conditions do they move, in appreciable numbers, to other or fringe areas which might be less desirable or suitable. After the pink salmon has spawned it dies.

The eggs thus deposited develop in the gravel. The time required for development of the egg and resulting alevin to the stage of a free-swimming fry depends largely upon temperature. The fry move up out of the gravel, emerging only as darkness approaches, and move downstream to the sea.

Once in the sea the pink salmon grows quickly and matures to an adult fish in 2 years (from time of fertilization of the egg). At maturity it returns, usually to its parent stream, to spawn and die.

CHUM SALMON

The freshwater phase of the life history of the chum salmon is almost identical with that of the pink salmon. Adult chum salmon usually enter the stream to spawn a little later than pink salmon but the range of creek water temperatures is the same. These fish are influenced by the same factors as are pink salmon in their upstream migration. The chum salmon distribute themselves over the gravel bars as do pink salmon with some extensions of their range into faster waters and heavier and coarser gravel. The spawning behavior of the chum salmon is the same as for pink salmon and like the pink salmon, the chum salmon, under crowded conditions moves into generally less suitable spawning locations. After spawning, the chum salmon dies.

The eggs and alevins in the gravel require about the same time for their development as the corresponding stages of pink salmon. Chum fry emerge from the gravel at darkness. Although some of these fry not uncommonly remain for a time in fresh water, an immediate migration to the sea is typical in Hooknose Creek, and in British Columbia generally.

The chum salmon fry after entering the sea grow at a rapid rate but do not mature as quickly as pink salmon. Maturity of chum salmon occurs at different

ages, usually at ages of 3, 4, and 5 years with the greatest number reaching this stage in their fourth year. These fish, upon reaching maturity, usually return to their parent streams to spawn and then die.

OTHER FISHES

Hooknose Creek is an island stream and consequently contains only fish that are diadromous or of euryhaline character. Apart from pink and chum salmon the following species are found in the stream:

Sockeye salmon	<i>Oncorhynchus nerka</i> (Walbaum)
Coho salmon	<i>Oncorhynchus kisutch</i> (Walbaum)
Dolly varden char	<i>Salvelinus alpinus malma</i> (Walbaum)
Cutthroat trout	<i>Salmo clarki clarki</i> Richardson
Steelhead trout	<i>Salmo gairdneri</i> Richardson
Prickly sculpin	<i>Cottus asper</i> Richardson
Aleutian sculpin	<i>Cottus aleuticus</i> (Gilbert)
Threespine stickleback	<i>Gasterosteus aculeatus</i> Linnaeus
Brook lamprey	<i>Lampetra ayresi</i> (Gunther)
Pacific lamprey	<i>Entosphenus tridentatus</i> (Gairdner)

These fishes are found in varying degrees of abundance. Their interrelationships as prey, predator and competitor influence the production of pink and chum salmon.

METHODS

The determination of survival and production of pink and chum salmon called for the counting of adult salmon entering the stream, determination of their egg content and the counting of fry passing downstream.

The adults moving upstream were counted through a picket weir situated just above tide water. A sample of the female salmon was taken for egg counts and subsequent calculation of the potential deposition of eggs in the stream. The fry were collected in a screen weir when they passed downstream in the spring. Both the upstream and downstream weir have been described by Hunter (1954). The fry collected during their downstream migration were either counted or weighed. In the latter event, the fish were sampled to obtain the proportion of pinks and chums and the average weight of individuals of each species.

The proportion of the species and their distribution in the stream were investigated by using a type of fyke net. These nets had a rectangular steel frame opening of 1 × 2 feet (30 × 61 cm) with an attached nylon mesh bag (mesh 0.125 inches or 3.17 mm in diameter). This mesh bag was 3.5 feet (106.7 cm) long and tapered from the steel frame to a removable collecting bucket 10 inches (25.4 cm) in diameter and 12 inches (30.5 cm) long. The collecting bucket was, apart from the metal top where it joined the bag, made of heavy cotton canvas

with a sleeve of fine-mesh nylon inserted. The efficiency of these nets was checked against counts from the weir. Although these nets were placed 200 yards upstream from the weir and thereby missed all fry emerging from gravel in this interval, correlation values of 0.9698 ($P = 0.418$; 35 pairs of observations) for pink salmon and 0.9807 ($P = 0.372$; 46 pairs of observations) for chum salmon were found between the catches made by the nets and the fry collected by the weir. A total of 46,319 pink fry and 279,420 chum fry were caught by the nets, amounting to 28.4% and 31.4% of the respective runs. The nets, in addition to providing an excellent means of sampling the emigrating pink and chum fry, provided a second measure of fry output. They were likewise found very useful in studying the time of migration, the behaviour of the fry in the stream and the relation of migrating fry to stream velocity and configuration.

The numbers of spawning pink and chum salmon in different parts of the stream were determined by periodic visual counts of salmon on the spawning gravel throughout the spawning season over the entire length of Hooknose Creek. The stream was divided into 100-yard sections and the fish were counted, by at least two observers at the same time. It was found that counts were lower than actual numbers known to have entered the stream but significant differences were not usually found between observers. Though absolute accuracy was lacking here, consistency between observers provided a reasonable basis for calculating the proportion of spawners in the different sections of the creek.

Marking and tagging of fry and adult pink and chum salmon has been conducted in Hooknose Creek at different times. Migrating fry were marked by the removal of the two pelvic fins. Fry were also marked by inserting fine silk threads under the dorsal fin. These thread marks were used in an effort to measure the amount of predation on the fry in the stream. The length of life of adult pink and chum salmon after they entered the stream was investigated by applying Petersen disc tags to fish at the weir.

Sculpins (*Cottus asper* Richardson) were marked by the removal of various fins. The recovery of marked fish provided a basis for certain population estimates as well as for tracing movement within the stream.

Pink and chum salmon redds were sampled by means of a wide hand seine held in the water downstream from the nest while the latter was being excavated. The exposed eggs and alevins were carried down current into the net.

Physical and meteorological records were made twice daily; at 9:00 hours and 17:00 hours. Pacific Standard Time. These morning and afternoon readings were supplemented with a recording thermograph and depth meter.

SPAWNING ESCAPEMENTS

SIZE OF ESCAPEMENTS

The magnitude of the spawning escapements of pink and chum salmon entering Hooknose Creek has varied considerably during the years it has been studied. The numbers of pink and chum salmon counted through the weir into Hooknose Creek are reported in Table I.

TABLE I. Numbers of pink and chum salmon entering Hooknose Creek to spawn.

Year	Number of pink salmon	Number of chum salmon	Combined number of pink and chum salmon
1947	5,576	10,191	15,767
1948	1,160	1,022	2,182
1949	1,173	718	1,891
1950	1,857	2,382	4,239
1951	1,670	1,329	2,999
1952	8,685	871	9,556
1953	1,599	4,355	5,954
1954	31,402	3,336	34,738
1955	1,310	1,219	2,529
1956	21,650	3,219	24,869
1957	2,333	3,131	5,464

SEX RATIOS

The sex ratio of the two species varied slightly from a 1:1 ratio during the years this study has been made (Table II). The greatest discrepancy from 1:1 ratio was no larger than 7.1 percent. However for both species there is an excess of females in most years which is significant for the period as a whole and for some individual years; the unweighted average is 53.3% females for pinks and 50.9% for chums.

TABLE II. Percentage of female pink and chum salmon comprising the total stocks in Hooknose Creek; see Table I for numbers of individuals.

Year	Percentage of female pink salmon	Percentage of female chum salmon
1947	52.5	51.6
1948	51.5	49.9
1949	44.6	49.6
1950	55.3	50.5
1951	52.6	55.4
1952	57.1	43.7
1953	55.6	51.2
1954	56.0	55.0
1955	55.7	50.9
1956	52.2	51.5

Most pink and chum salmon in this region are caught by seine nets which would be relatively non-selective for sexes. Determination of the sex of 232 pink salmon fry migrating from Hooknose Creek showed a ratio 52% males to 48% females, Robertson (MS, 1951).

EFFECT OF STREAM DISCHARGE AND WATER TEMPERATURE

The upstream spawning migration of pink and chum salmon occurs over a period of approximately two months. Daily fluctuations in the numbers moving upstream occurs over this period. These daily fluctuations are shown in Fig. 1 and 2.

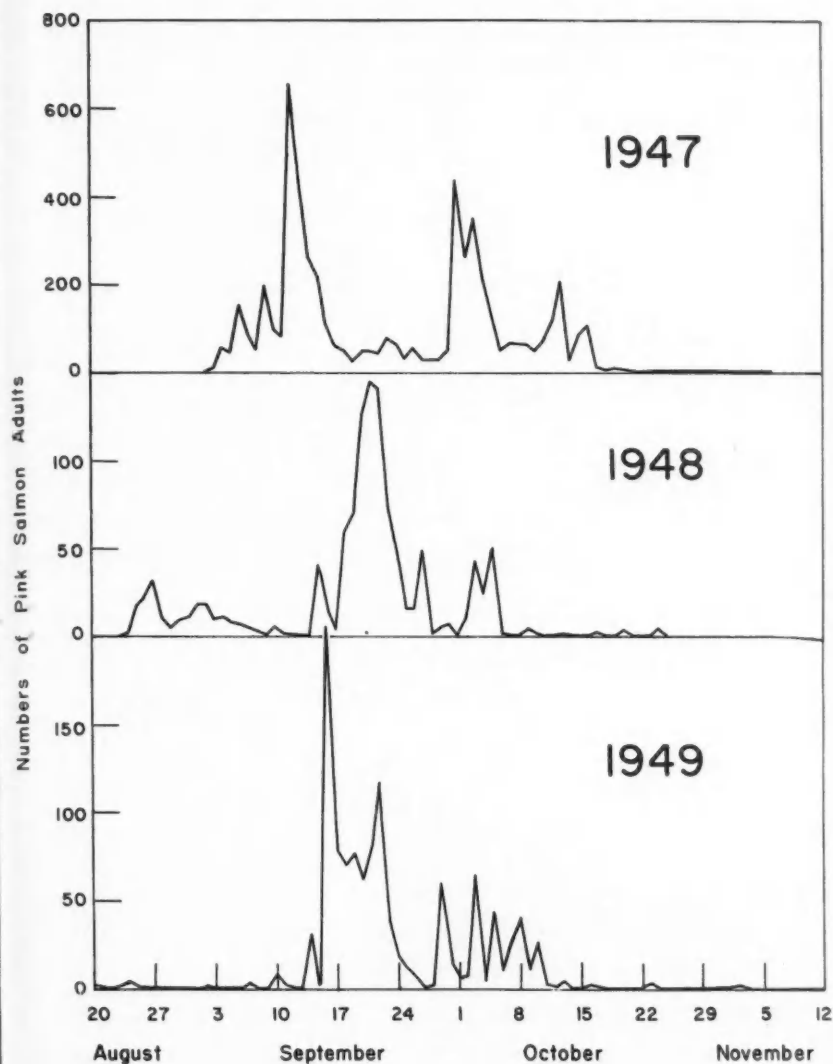


FIG. 1. Numbers of pink salmon entering Hooknose Creek to spawn.

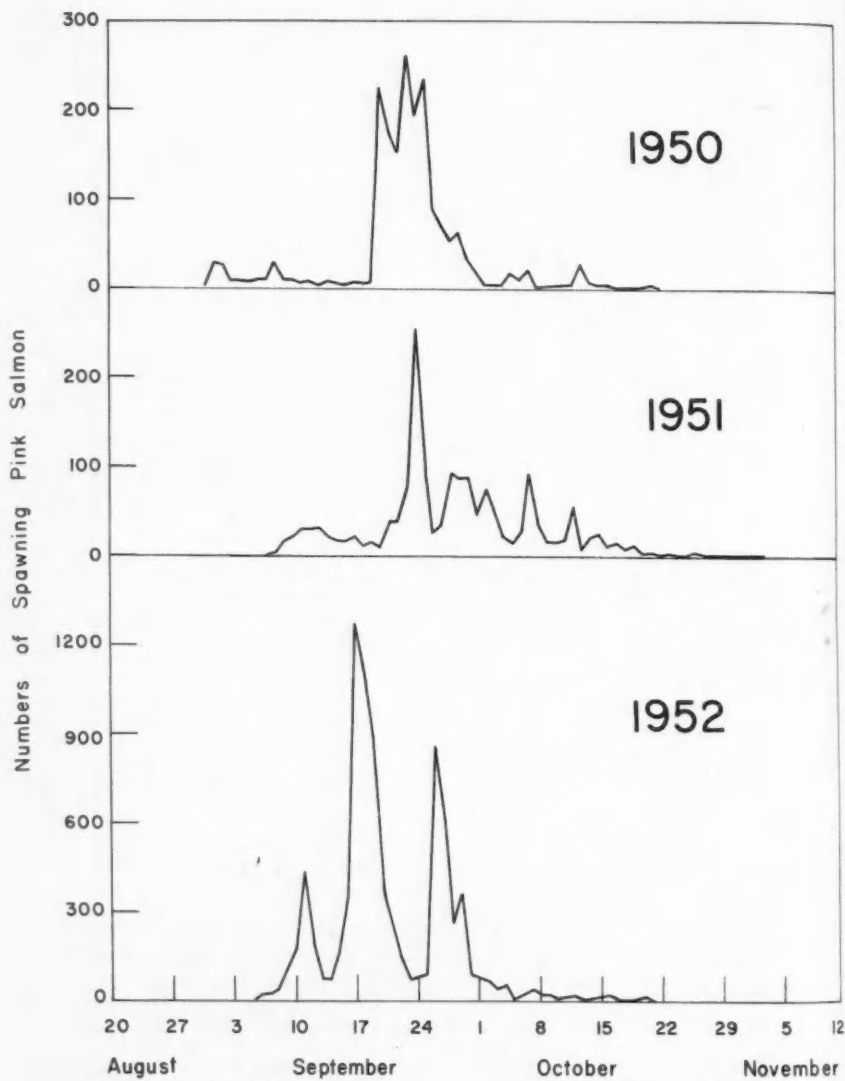


FIG. 1 (continued). Numbers of pink salmon entering Hooknose Creek to spawn.

Among the factors controlling the upstream movement of adult pink and chum salmon the stream discharge was found to have an important effect.

A measure of this effect of fluctuating water levels on the upstream migration of pink salmon is shown by fitting a 3rd degree polynomial curve to the complete 1952 escapement and correlating the differences between the smoothed and actual daily upstream migration of pink salmon with the water discharge of that and the previous day. The fitted polynomial curve, the actual count and the stream discharge for the same day are shown in Fig. 3.

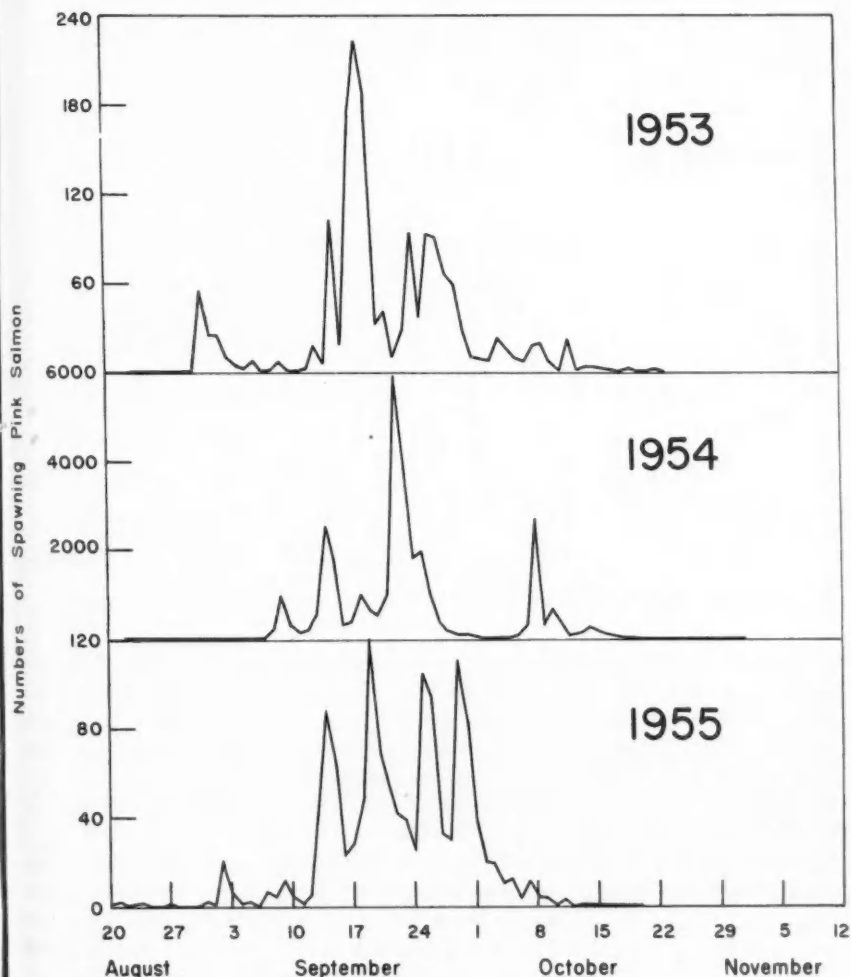


FIG. 1 (continued). Numbers of pink salmon entering Hooknose Creek to spawn.

Correlation of these differences with water discharge figures for the same day show a significant relation at the 99% probability level with 49 degrees of freedom, $r = 0.5843$. This suggests that about 34% of the variation in upstream movement (apart from seasonal trend) was associated with the level of stream discharge as measured the same day (or associated phenomena). Correlation of the above differences with water discharge of the day previous to entry also shows a significant relation, $r = 0.4397$. This indicates that about 19% of the

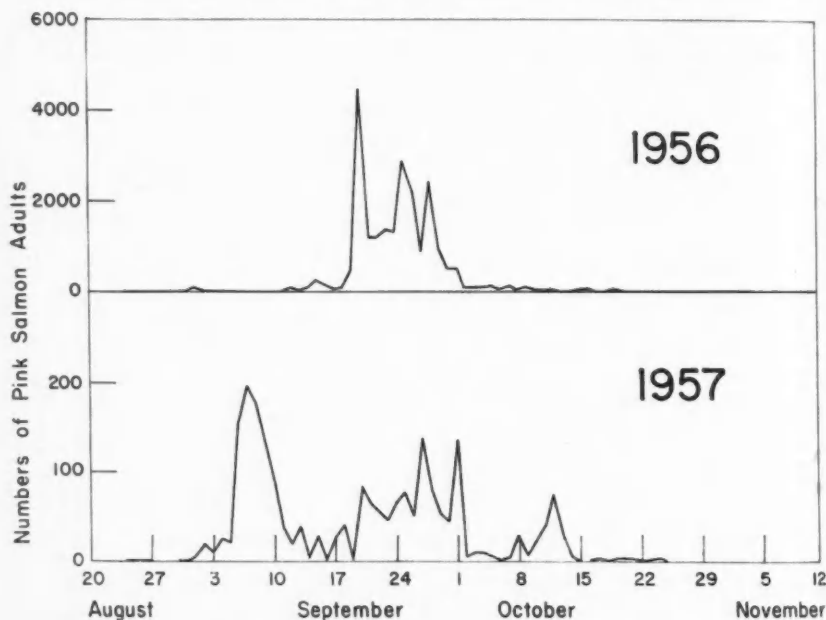


FIG. 1 (continued). Numbers of pink salmon entering Hooknose Creek to spawn.

variation in upstream movement was associated with stream discharge of the day previous to their entry (or associated phenomena—there may, of course, be a correlation between discharges of successive days). These calculations have been made for pink salmon for one year only but the relationship for both pink and chum salmon was evident from gross observation throughout the period of this investigation. Fig. 4 shows the Hooknose Creek water discharge and temperature for the spawning periods from 1947 to 1956.

After arriving in the bay off Hooknose Creek, pink and chum salmon may spend considerable time there before entering the stream. Since Hooknose Creek drains from a lake, its discharge is regulated to the extent that spawning fish can enter at almost any time and are not dependent upon flood water levels to travel in the creek. Also, all fish do not enter when water levels are high, nor do they fail to move upstream if prolonged dry periods exist. Thus, although they respond

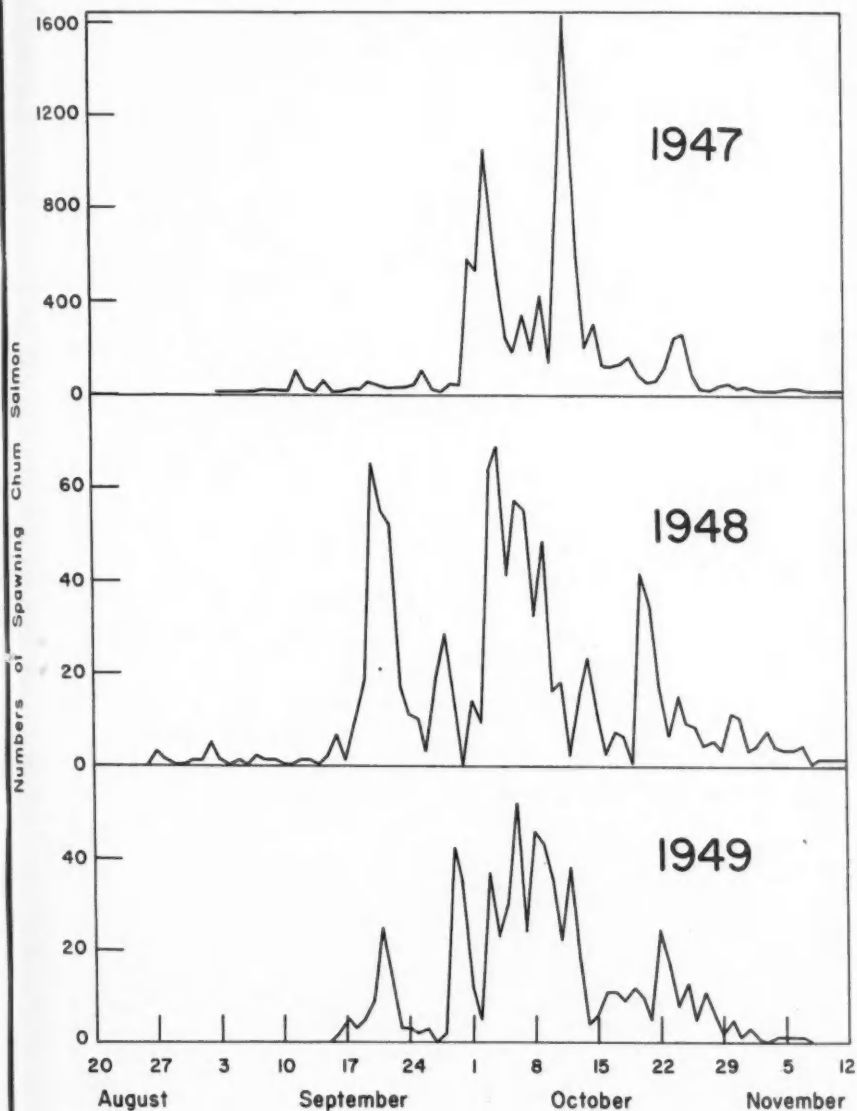


FIG. 2. Numbers of chum salmon entering Hooknose Creek to spawn.

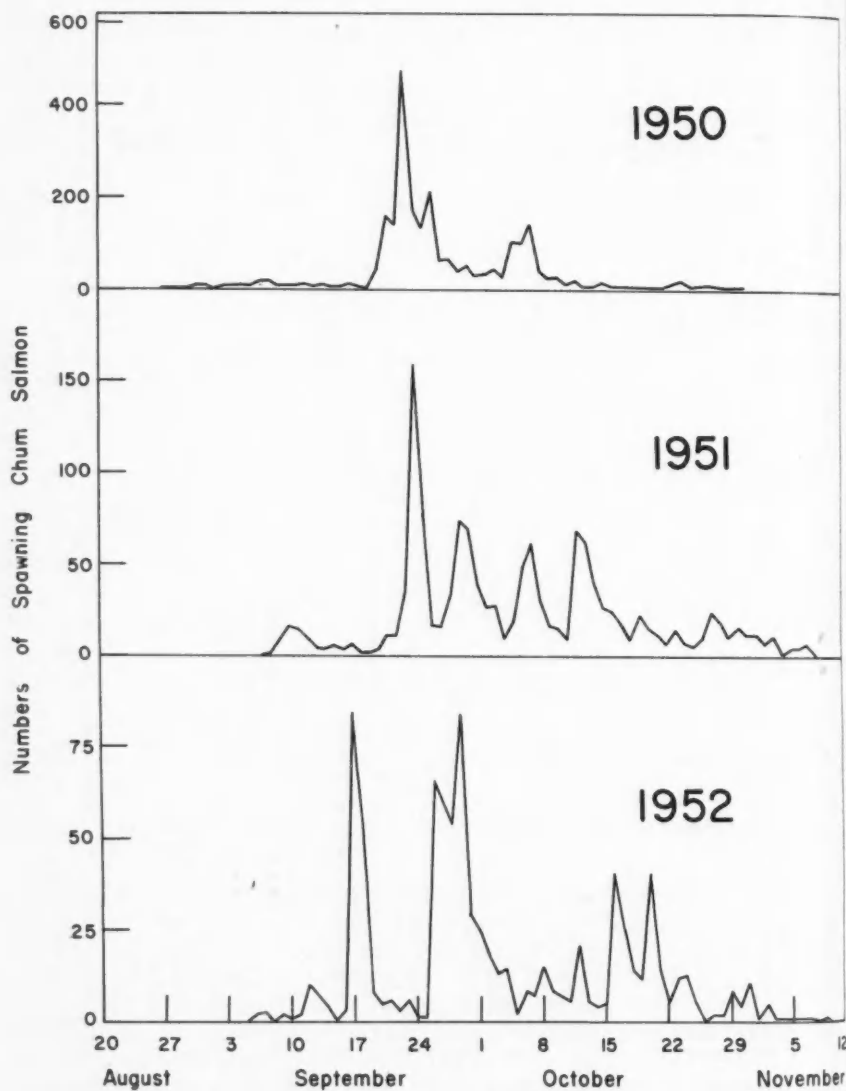


FIG. 2 (continued). Numbers of chum salmon entering Hooknose Creek to spawn.

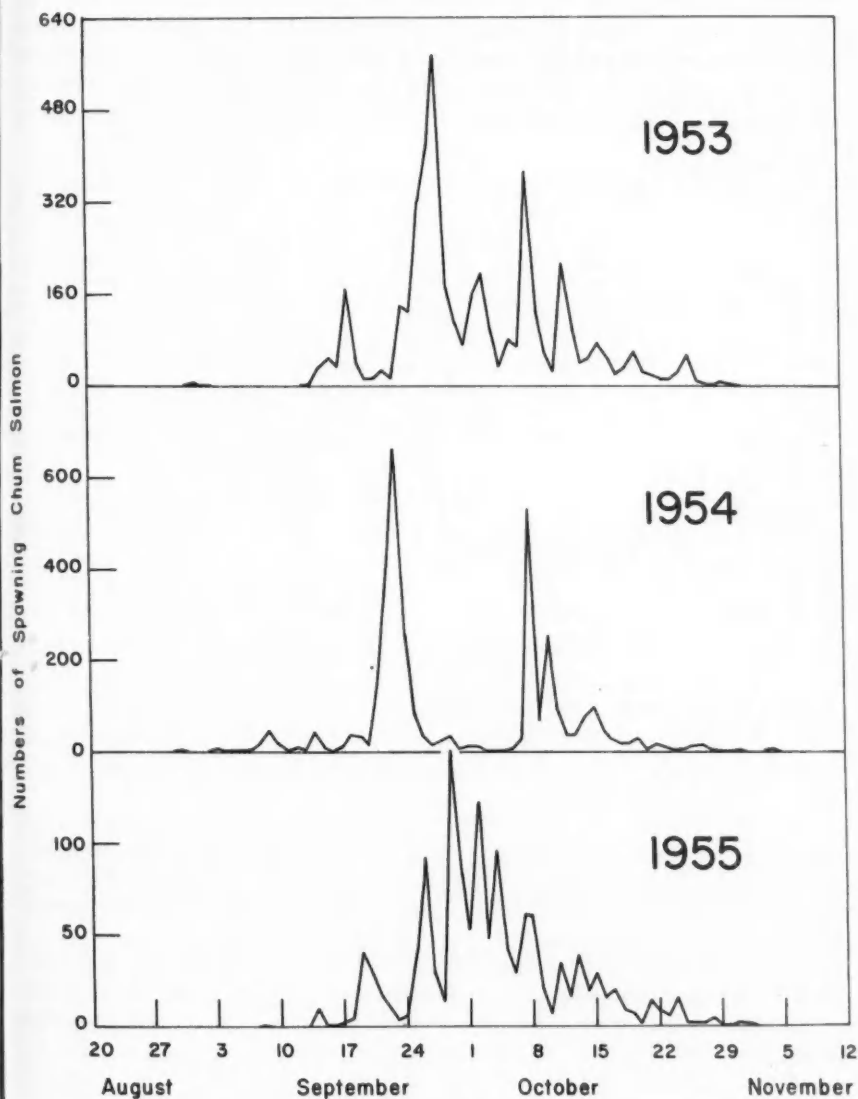


FIG. 2 (continued). Numbers of chum salmon entering Hooknose Creek to spawn.

to some degree to flood water conditions they are not dependent on such conditions for moving upstream. In fact the fish do not migrate upstream at excessive flood levels but seem to have a maximum current against which they will travel. Similar observations were made by Pritchard (1936) for pink salmon in McClinton Creek, B.C. and by Davidson *et al.* (1943) for Sashin Creek in southeast Alaska. Davidson *et al.* state that for Snake Creek in southeastern Alaska pink salmon

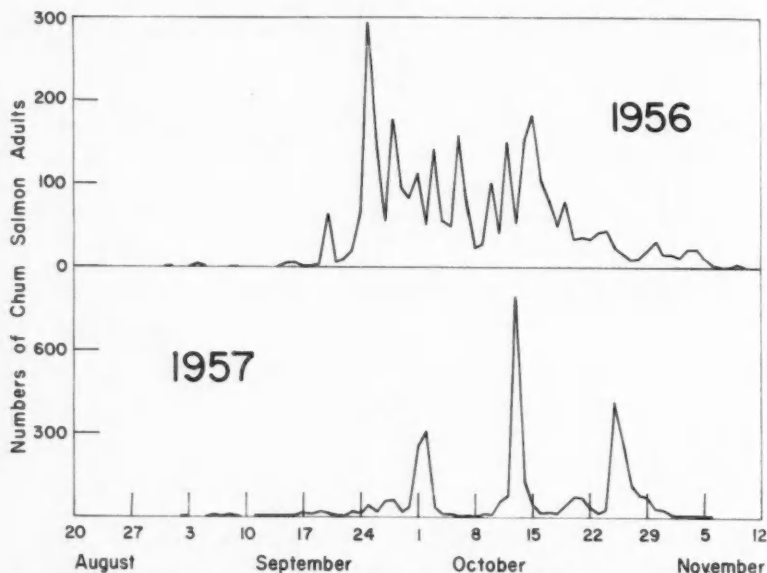


Fig. 2 (continued). Numbers of chum salmon entering Hooknose Creek to spawn.

are able and do enter the stream on arrival in the bay with the exception of periods of high water. These fish do not respond to fluctuations of stream discharge and the authors consider this as a result of a difference in the inherent behavior pattern of the Snake Creek pink salmon.

Hooknose Creek water temperatures did not appear to produce any noticeable effect on the upstream movements of pink and chum salmon. Stream temperatures of Hooknose Creek for the spawning periods of the years 1947 to 1956 are shown in Fig. 4.

TIME OF STREAM ENTRY OF SPAWNING PINK AND CHUM SALMON

The timing of the runs of pink and chum salmon in Hooknose Creek is about the same for each year (Fig. 1, 2). Taking the mean time of entry as the point at which 50% of the spawning fish have entered the stream, Table III has been constructed to show the variation that does occur from year to year.

Table III shows that the variation in the date at which 50% of the adult fish enter the stream to spawn is not great. Pink salmon show a greater consistency in time of 50% arrival than chum salmon. Such might be expected since the chum salmon escapement is composed of three age groups, with the youngest age

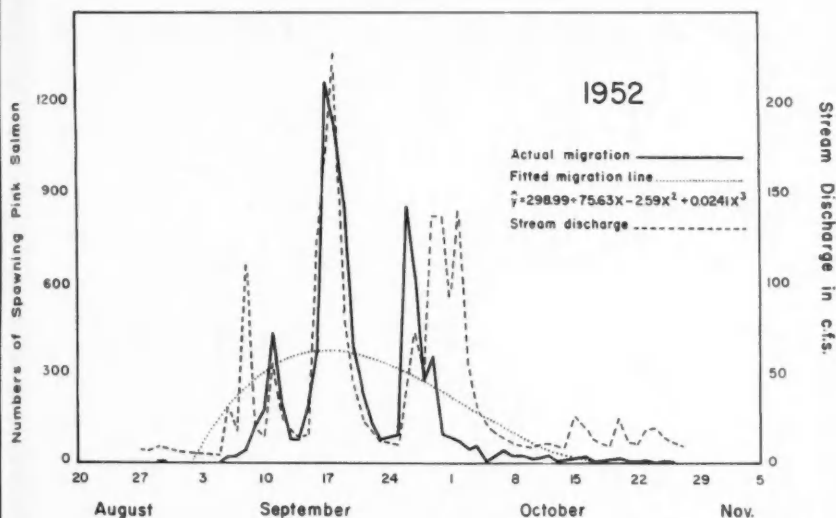


FIG. 3. Relation of stream discharge and pink salmon upstream migration in Hooknose Creek.

group the last to enter the stream and the oldest the first to enter, on the average. The 50% level of entry would be expected to vary with the proportion of the different age groups comprising the stock.

DISTRIBUTION OF SALMON THROUGHOUT THE STREAM

Counting pink and chum salmon in the different sections of Hooknose Creek shows that preferred locations exist and that distribution of the spawning fish is

TABLE III. Date on which 50% of pink salmon and chum salmon had entered Hooknose Creek.

Brood year	Pinks	Chums
1947	September 20	October 10
1948	September 20	October 4
1949	September 20	October 8
1950	September 23	September 25
1951	September 27	October 3
1952	September 18	September 29
1953	September 19	September 30
1954	September 22	September 24
1955	September 22	October 2
1956	September 24	October 6

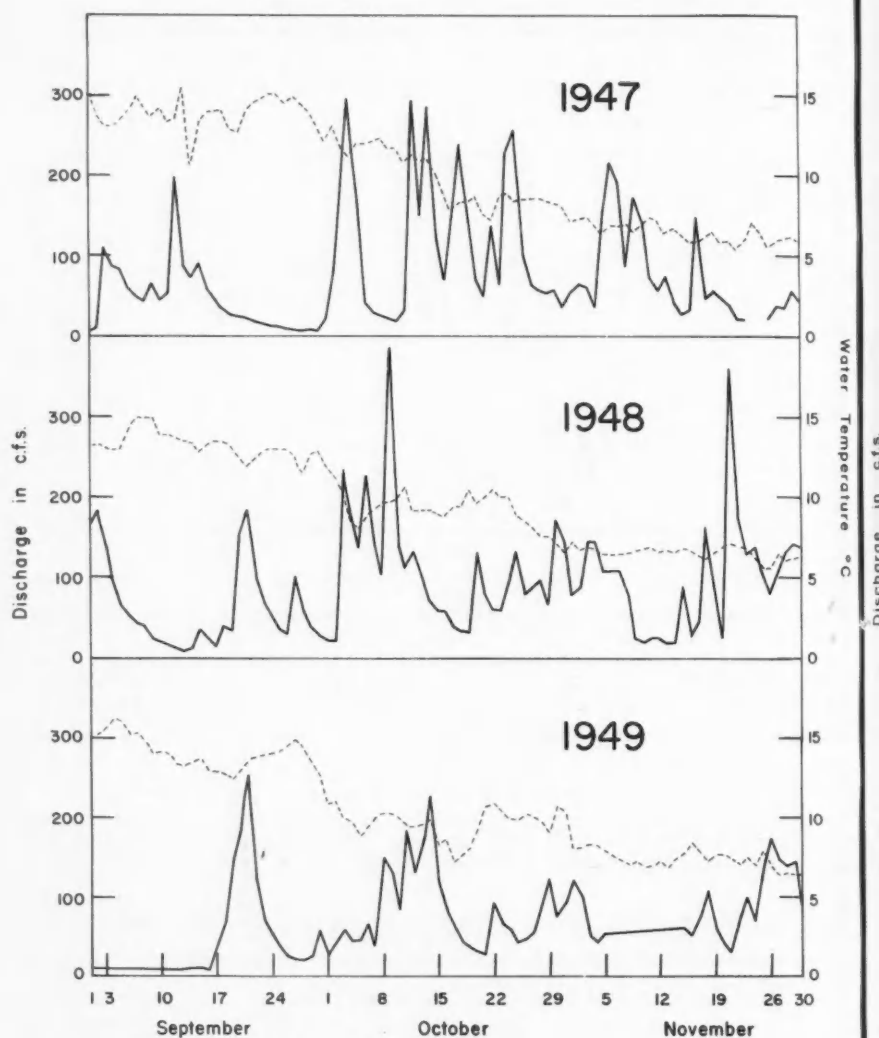


FIG. 4. Water discharge and water temperature in Hooknose Creek. Solid line—discharge; broken line—temperature.

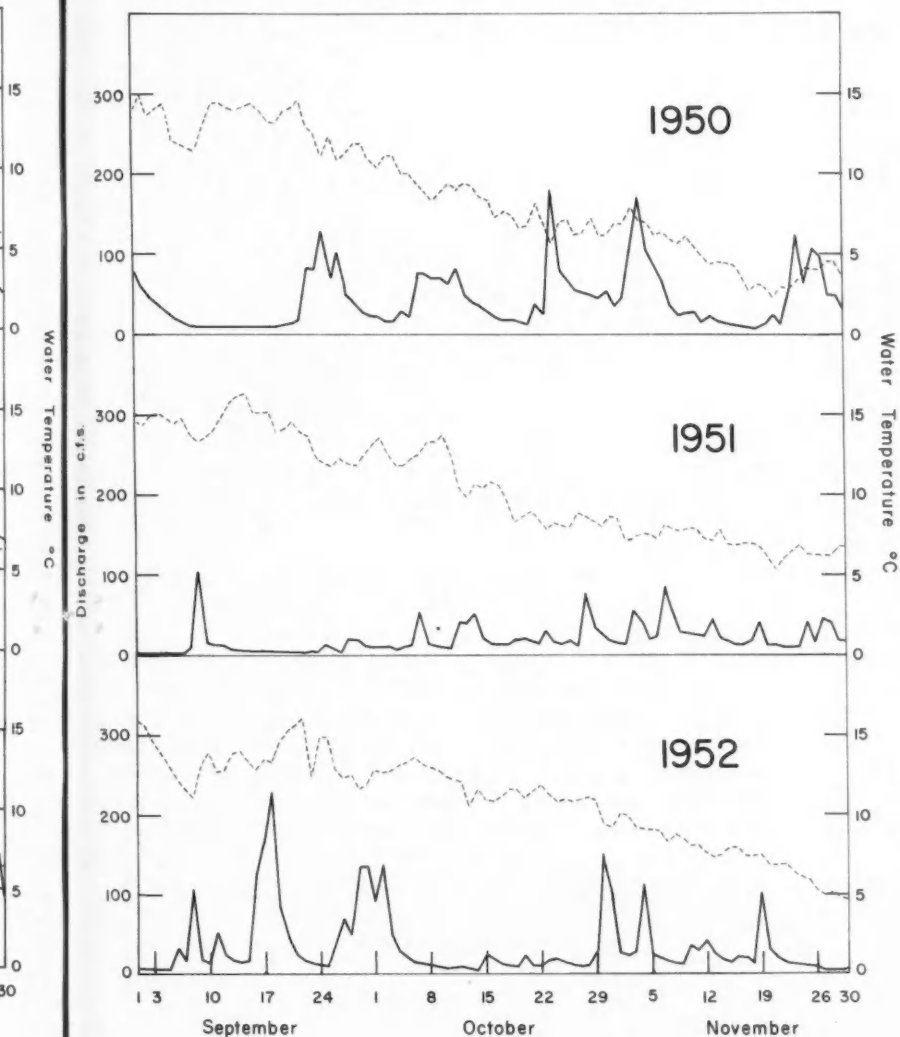


FIG. 4 (continued). Water discharge and water temperature in Hooknose Creek.

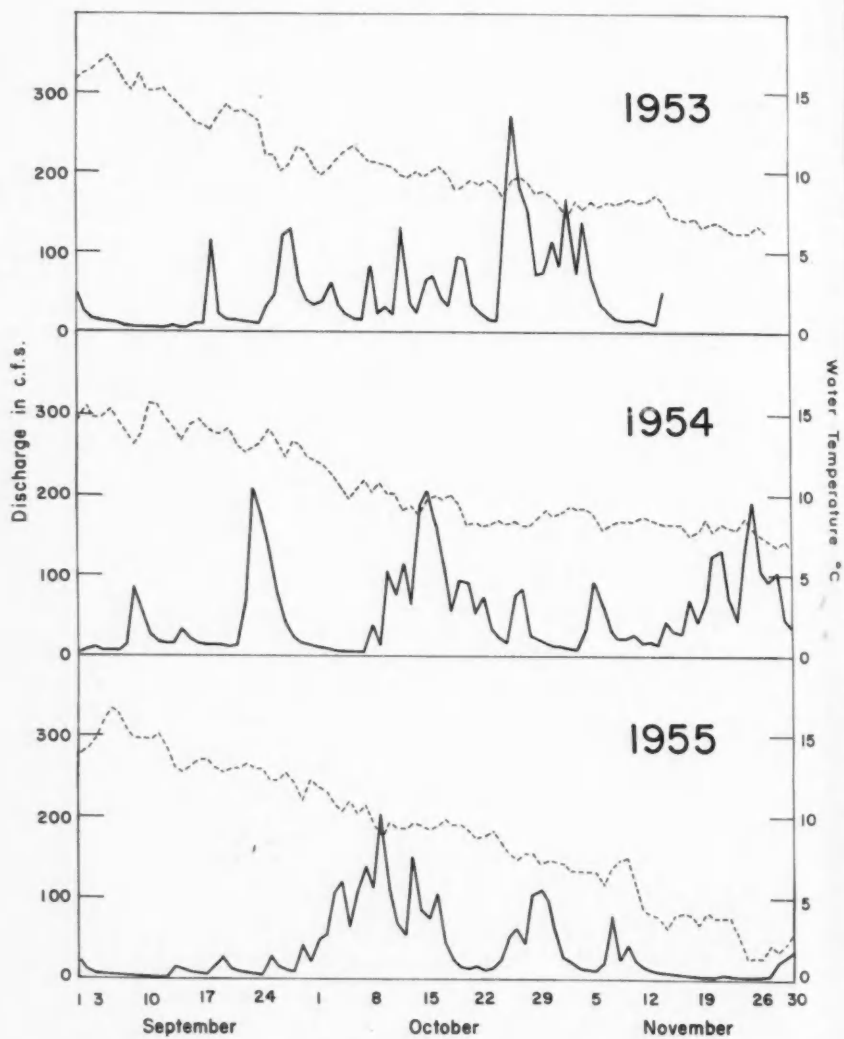


FIG. 4 (continued). Water discharge and water temperature in Hooknose Creek.

not continuous. Fig. 5 shows a map of Hooknose Creek with the percentage of pink and chum salmon spawning in each section based on four years of examination.

It has been found consistently that relatively high proportions of the run spawn in certain areas of the stream while other areas have a low percentage

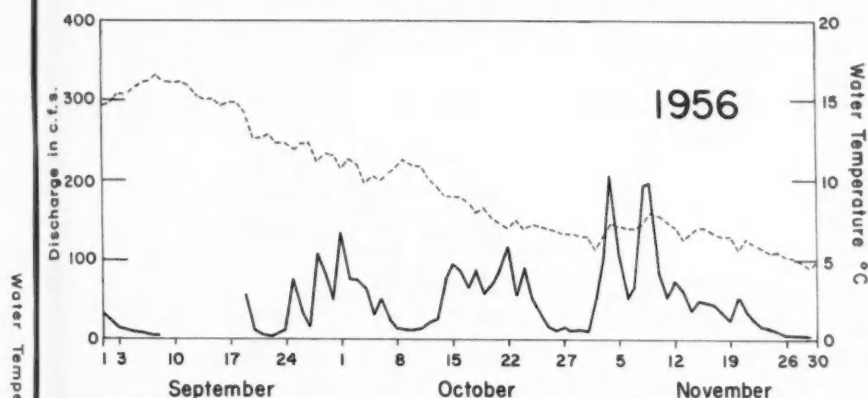


FIG. 4 (continued). Water discharge and water temperature in Hooknose Creek.

of the run. The small difference of choice of sections between pink and chum salmon is shown in Fig. 5.

Numerous streams along the coast have low-lying areas which are affected by tidal changes. Hooknose Creek is of this type. The weir at Hooknose Creek is situated just above the level to which brackish water reaches when high tides occur. Although many salmon spawn in these intertidal regions the exact number is not known. The best estimates available are from visual counts of fish in the stream. A 200-yard interval of intertidal region of Hooknose Creek used as spawning ground usually carries approximately 15% of the escapement above the weir of both pink and chum salmon; in 1954, when an exceptionally large escapement occurred, it was only 8%.

When population density becomes great both pink and chum salmon will move into fringe spawning grounds. Occasionally some fish will travel up to the lake and through the latter into its tributary streams.

EGG CONTENT AND DEPOSITION

EGG CONTENT

Counts of the egg contents of female pink and chum salmon have been made at Hooknose Creek during every year of its operation. These counts are shown in Table IV.

The female fish were a regular sample from the run passing through the weir, regardless of whether they were partially spawned or not. Therefore they do not

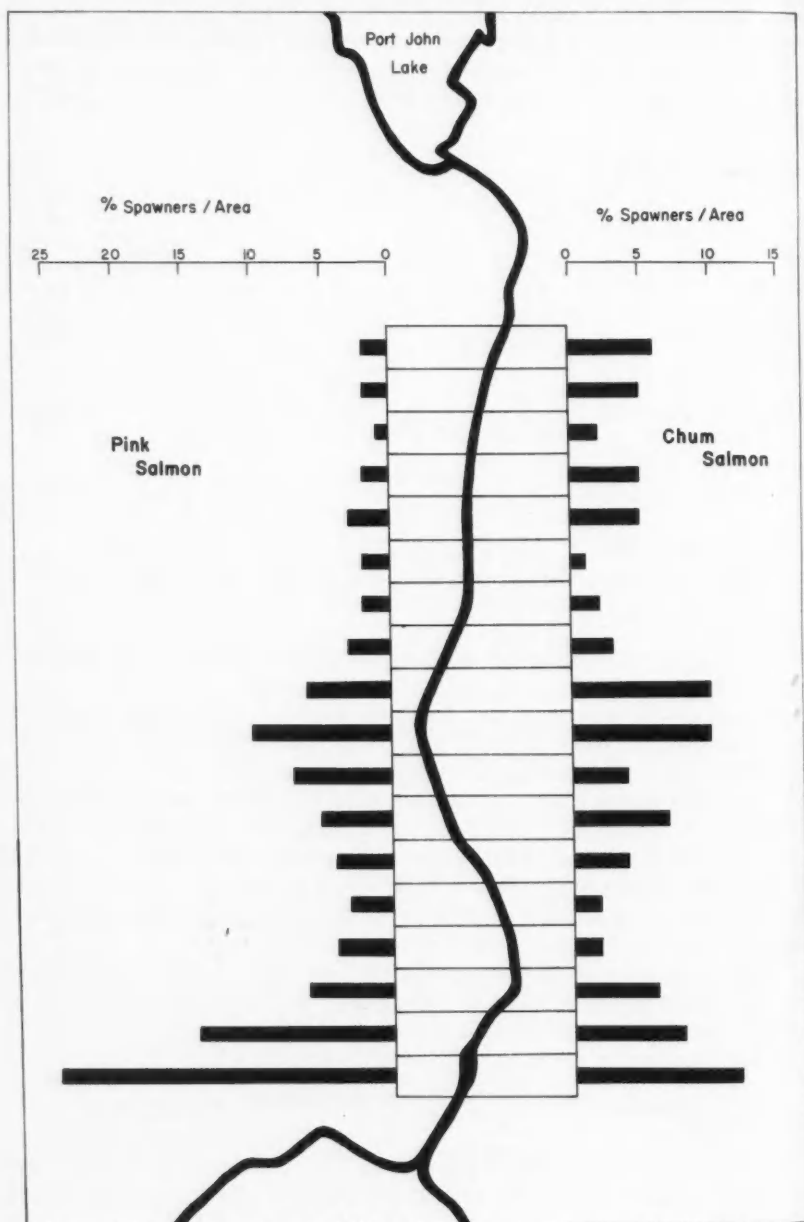


FIG. 5. Distribution by 100 yard intervals of spawning pink and chum salmon in Hook-nose Creek.

provide an accurate measure of the eggs carried by the unspawned fish but rather a figure for the average number of eggs for female fish going upstream to spawn. The potential deposition of eggs has been calculated using these average figures.

TABLE IV. Number of samples, average egg content and standard error of egg content of pink and chum salmon sampled in Hooknose Creek. (Some of the females used were partially spent.)

Year	Pinks		Chums	
	No. in sample	Av. egg count	No. in sample	Av. egg count
1947	47	1316 \pm 78	85	2107 \pm 67
1948	10	1341 \pm 94	8	2101 \pm 127
1949	15	1650 \pm 57	13	2083 \pm 129
1950	22	1543 \pm 189	19	2406 \pm 71
1951	15	1708 \pm 54	11	2201 \pm 168
1952	80	1771 \pm 42	6	2728 \pm 161
1953	11	1672 \pm 94	35	2741 \pm 68
1954	177	1666 \pm 22	22	3097 \pm 113
1955	9	1833 \pm 91	8	2604 \pm 212
1956	113	1426 \pm 24	31	2613 \pm 112

Generally every 60th female of each species was taken as a sample; in years of a large spawning escapement only one in a hundred females was sampled. In this way an average egg count was calculated which took into consideration both the variable egg counts of individuals and the fact that some fish had extruded some of their eggs.

CALCULATION OF EGG DEPOSITION

The egg deposition in Hooknose Creek above the weir was determined by multiplying the average egg content by the number of female spawning fish in the stream. A few fish were killed at the weir by accidents and floods; their numbers never assumed significant proportions. Also the number of spawning fish was reduced by taking samples for egg counts. The number of fish so killed has been deducted from the counts made at the weir to provide a figure for the total number of spawning female fish. The deposition of eggs is shown in Table V.

TABLE V. Calculated potential deposition of pink and chum salmon eggs in Hooknose Creek.

Year	Pink salmon	Chum salmon	Pink and chum salmon
1947	3,789,000	10,977,000	14,766,000
1948	787,000	1,055,000	1,842,000
1949	838,000	714,000	1,552,000
1950	1,551,000	2,858,000	4,409,000
1951	1,476,000	1,594,000	3,070,000
1952	8,511,000	938,000	9,449,000
1953	1,465,000	6,016,000	7,481,000
1954	28,201,000	5,581,000	33,782,000
1955	1,276,000	1,276,000	2,552,000
1956	14,471,000	3,805,000	18,275,000

Some fish may die before spawning, giving a lower deposition than actually calculated. This loss is regarded as part of the mortality of the potential deposition. The percentage survival of the pink and chum salmon eggs to the fry stage is based upon the number of eggs carried into the stream, as shown in Table V, and the numbers of resulting fry counted through the weir in the spring. Other losses occur right through the deposition, incubation and free swimming fry stages.

EGG RETENTION

Among the early causes of mortality is that due to incomplete spawning by the female. The numbers of eggs retained by female pink and chum salmon is shown in Table VI.

TABLE VI. Numbers of female pink and chum salmon examined, mean number of eggs retained and percentage egg retention per female.

Year	Pink salmon			Chum salmon		
	No. in sample	Mean no. of eggs retained	Percentage of eggs retained	No. in sample	Mean no. of eggs retained	Percentage of eggs retained
1951	18	45.9	2.7	42	104.1	4.7
1952	46	16.9	1.0	31	12.8	0.5
1953	43	2.1	0.1	37	18.2	0.7
1954	598	33.8	2.0	165	35.5	1.2
1955	126	5.5	0.3	60	5.4	0.2
1956	926	15.6	1.1	196	39.4	1.5

The foregoing table shows that egg retention after spawning does not reach significant proportions in Hooknose Creek. Semko (1951) reports egg losses by retention for chum salmon to increase in years of higher spawning density in the Bolshaya River in the U.S.S.R. This was not evident in Hooknose Creek.

EGG LOSSES IN REDDS

Examination of redds following the large escapements of 1947 and 1954, showed very high mortality had occurred. A few redd samples were taken by winter caretakers and others at Hooknose Creek during the intervening years but the samples were too few, small, and selected to give a reliable picture of survival in the creek, although all showed less mortality than the two years mentioned. The mortality found for combined pink and chum salmon eggs and alevins in the redd samples taken in January 1948 and January 1955 and the potential deposition in the stream for these two years is shown in Table VII.

The percentage mortality as determined by the dead eggs and alevins in the redd samples for 1947 and 1954 is slightly greater than has been determined from fry emergence calculations for these broods, but the redd samples considered do not include fringe area spawning.

TABLE VII. Numbers of redd samples, numbers of pink and chum eggs in samples, number of eggs dead in sample, percentage mortality in samples and potential deposition of eggs in Hooknose Creek.

Brood year	No. of samples	No. of eggs in sample	No. of eggs and alevins dead in sample	Percentage of eggs and alevins dead	Potential deposition
1947	10	1767	1657	93.6	14,766,000
1954	20	1784	1750	97.9	33,781,000

FRINGE AREAS

Fringe areas are those regions which might not consistently provide spawning area either by being exposed or by being exceptionally poor gravel or by having extreme water velocities. In 1954 three samples were taken in the fringe areas, not considered in Table VII, and they showed only 53.4% mortality, on the average. One of these three samples showed only 8.0% mortality.

TIME OF LOSSES

An analysis of the 1948 samples showed that 95.9% of the losses which occurred in the gravel happened in the pre-eyed stage of egg development. Causes of mortality of eggs and alevins in the gravel during incubation and development are numerous. A general outline listing these causes is given by Neave (1953).

FRY ESCAPEMENT

TOTAL NUMBERS OF FRY MIGRATING

The weir for collecting fry at Hooknose Creek was installed about the middle of March before the pink and chum salmon fry began their downstream migration. The fry which came downstream each night were tallied and released the following morning. The numbers of pink and chum fry going downstream through the weir each year are shown in Table VIII.

DAILY MIGRATION

The daily migrations of pink and chum salmon fry for the brood years 1947 to 1955 are shown in Fig. 6 and 7.

TABLE VIII. Numbers of pink and chum salmon fry passing through Hooknose Creek weir.

Brood year	Pink	Chum	Total
1947	33,349	108,746	142,095
1948	64,312	77,539	141,851
1949	54,061	44,463	98,524
1950	234,396	431,399	665,795
1951	242,993	269,701	512,694
1952	1,227,025	182,200	1,409,225
1953	204,250	984,504	1,188,754
1954	907,458	353,761	1,261,219
1955	86,256	49,443	135,699
1956	454,148	69,830	523,978

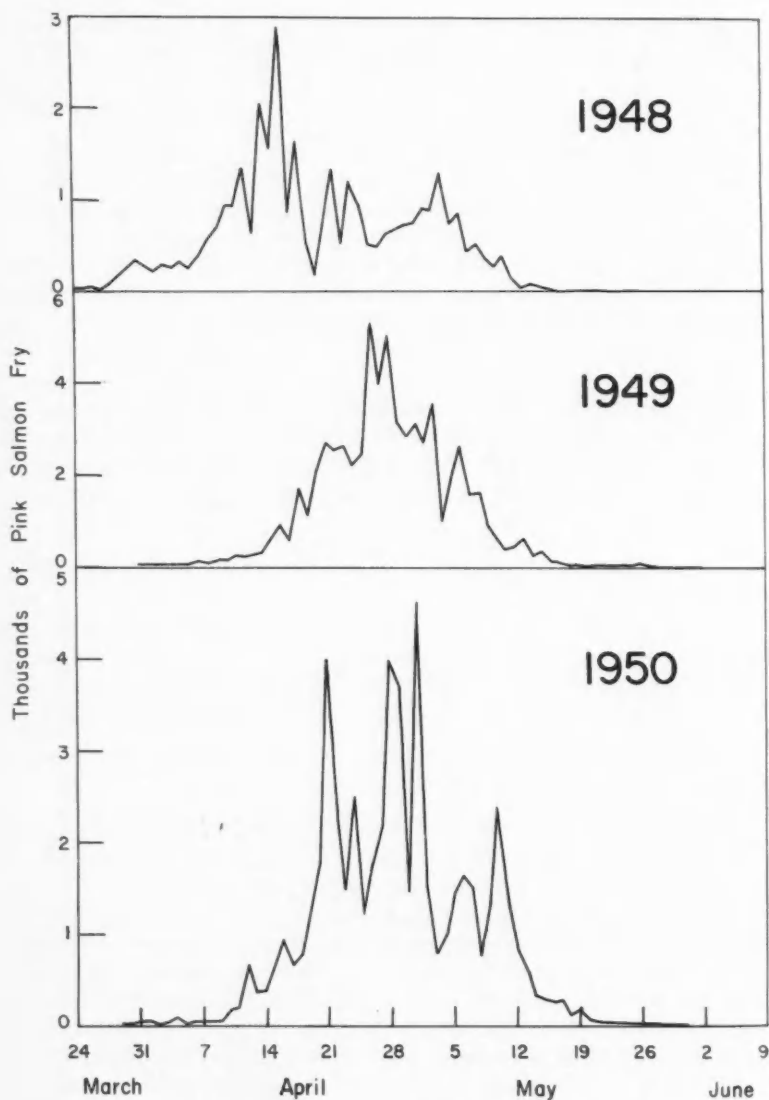


FIG. 6. Daily migration of pink salmon fry from Hooknose Creek.

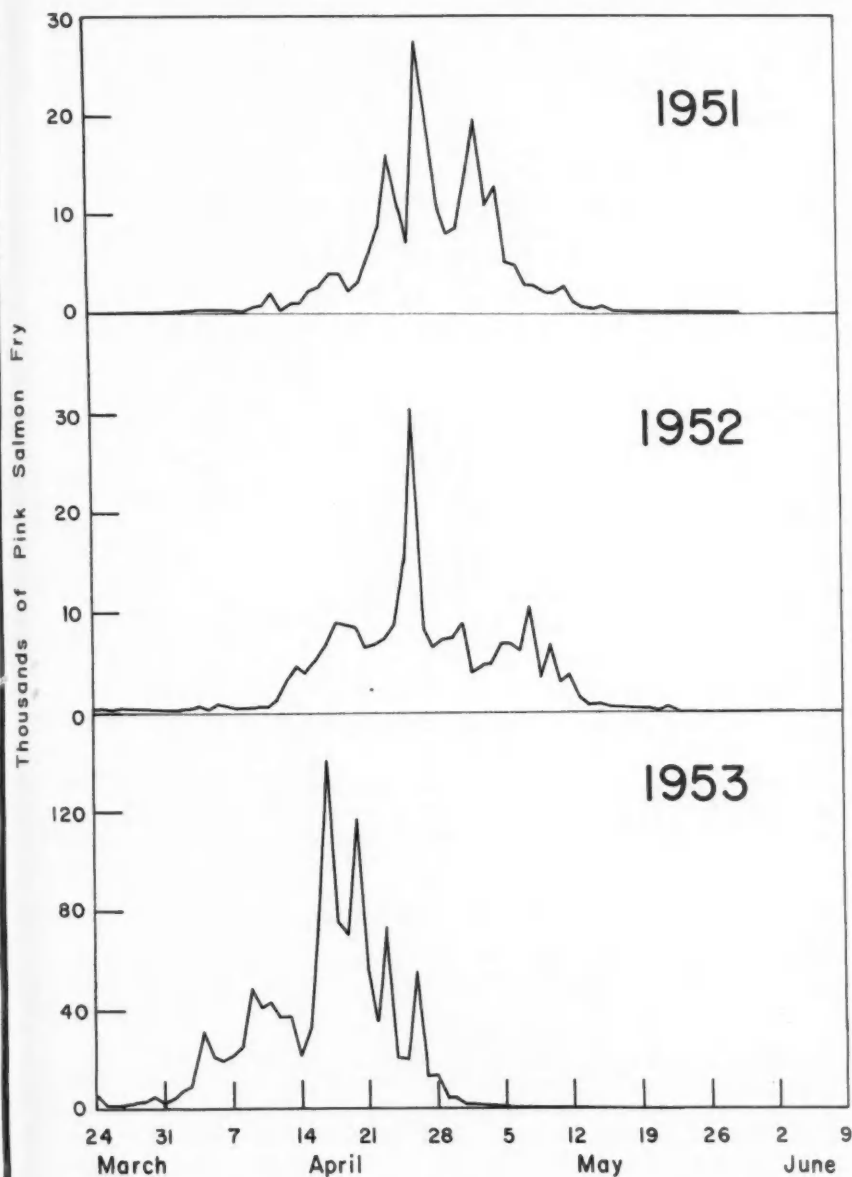


FIG. 6 (continued). Daily migration of pink salmon fry from Hooknose Creek.

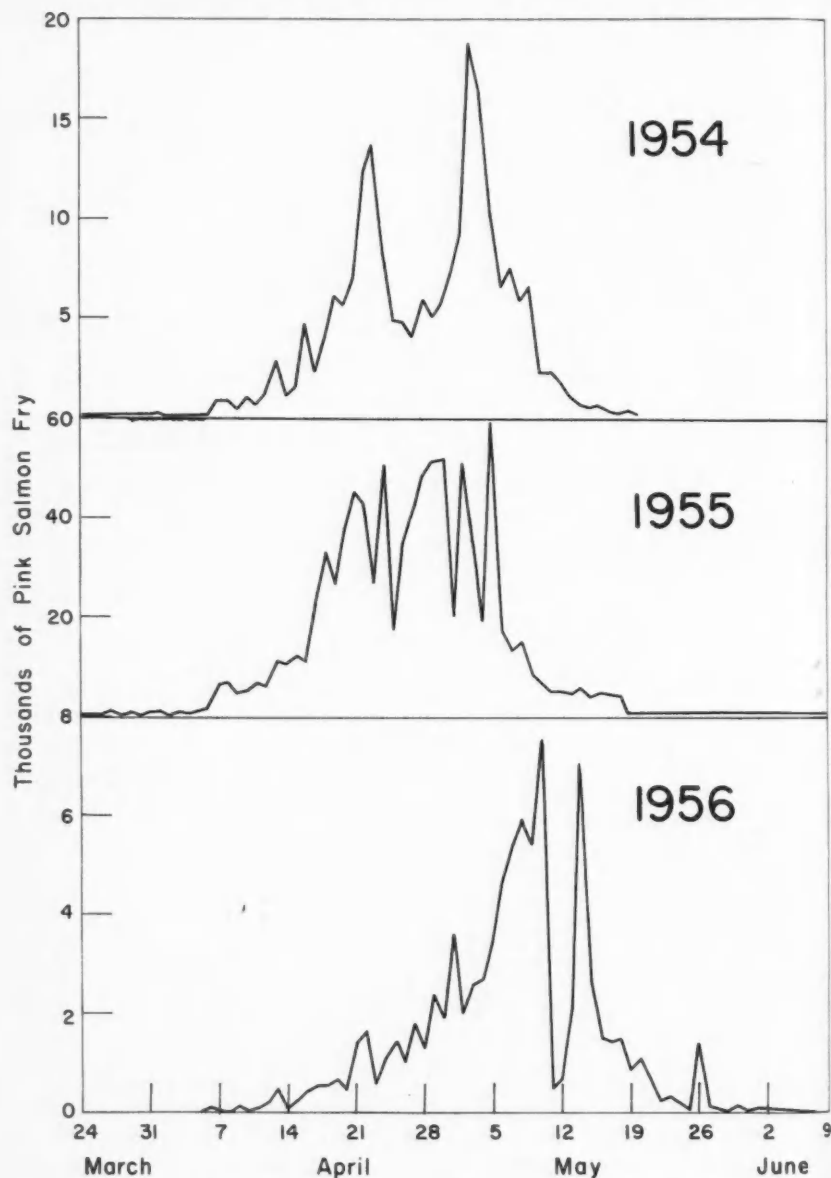


FIG. 6 (continued). Daily migration of pink salmon fry from Hooknose Creek.

The daily migration of combined pink and chum salmon fry is shown in Fig. 9.

Fluctuations in the numbers of fry migrating daily are caused to a considerable extent by variations in discharge level, temperature and light intensity.

DIURNAL PERIOD OF MIGRATION

The fry begin their downstream movement as darkness approaches, their numbers reach a peak and then start declining so that practically the entire migration is complete by 03:00 hours. Pink and chum fry have slightly different timing to their downstream migration. Fyke nets were used to measure the numbers

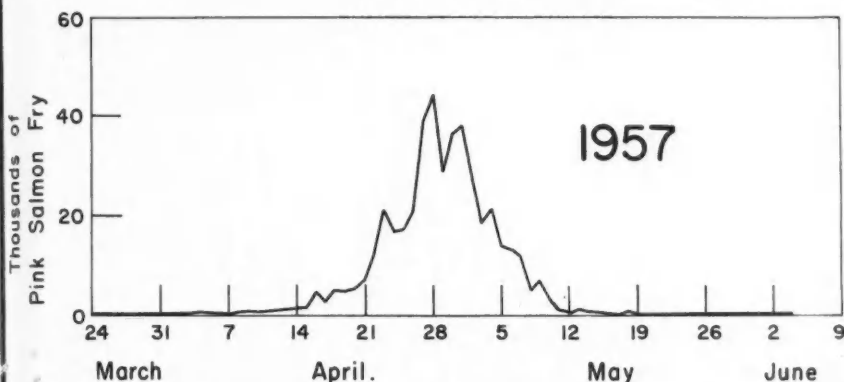


FIG. 6 (continued). Daily migration of pink salmon fry from Hooknose Creek.

per hour at which these fry migrated. The average values of 36 observations for pink salmon fry and 48 observations for chum salmon fry show the pink fry begin and end the main period of their nightly emigration about an hour ahead of the chum fry. (See Fig. 8, page 866.)

VERTICAL AND HORIZONTAL DISTRIBUTION OF MIGRATING FRY IN THE STREAM

Fyke nets were also used to determine the position of the fry in the stream during their migration. Table IX shows the vertical distribution of the migrating pink and chum salmon fry in the stream.

TABLE IX. Percentage of migrating pink and chum salmon fry at depth intervals at the centre and one-third way across Hooknose Creek. Percentages are average of measurements taken from May 12 to 21, 1954. The depth of the water was 13 inches (33 cm.) in both locations.

Location: Depth interval from surface of water, in inches	Centre			$\frac{1}{3}$ across		
	3	6	9	3	6	9
Pink	76.2	83.3	96.9	62.9	92.4	93.9
Chum	71.5	82.0	95.8	62.5	89.5	97.1

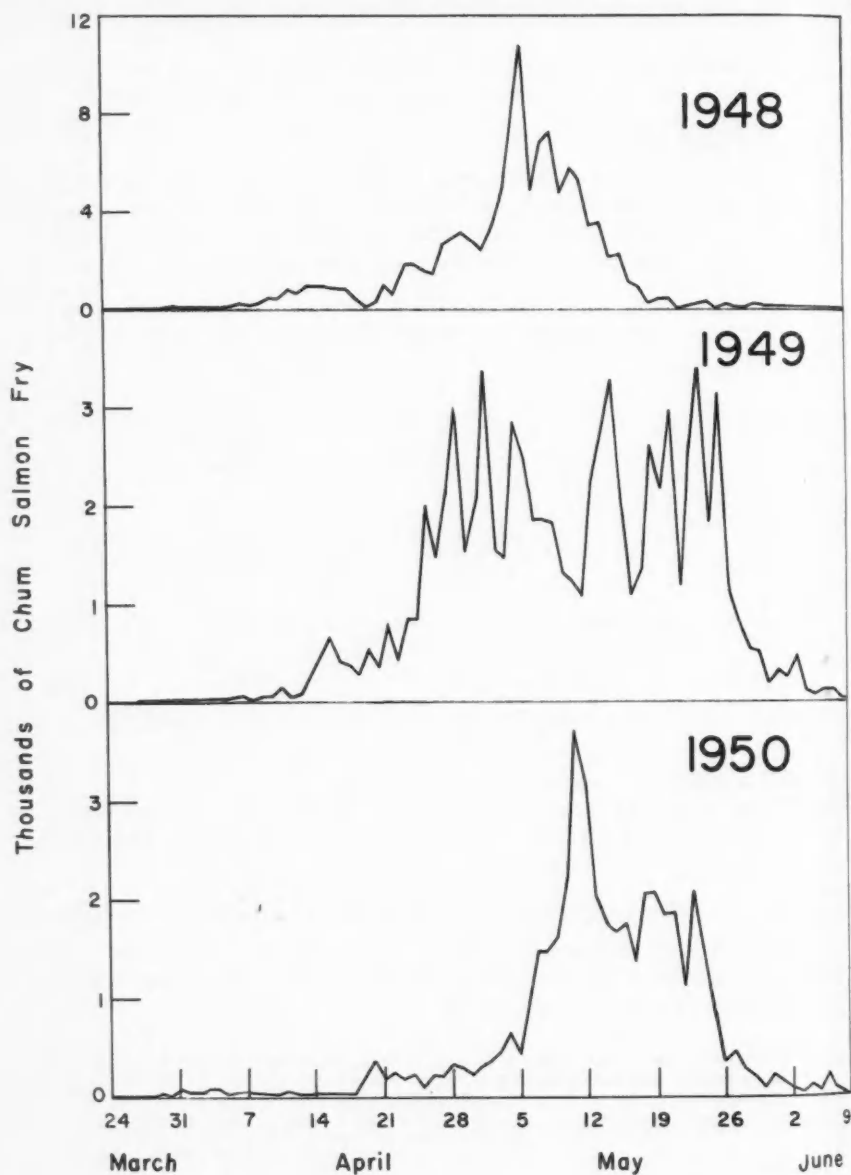


FIG. 7. Daily migration of chum salmon fry from Hooknose Creek.

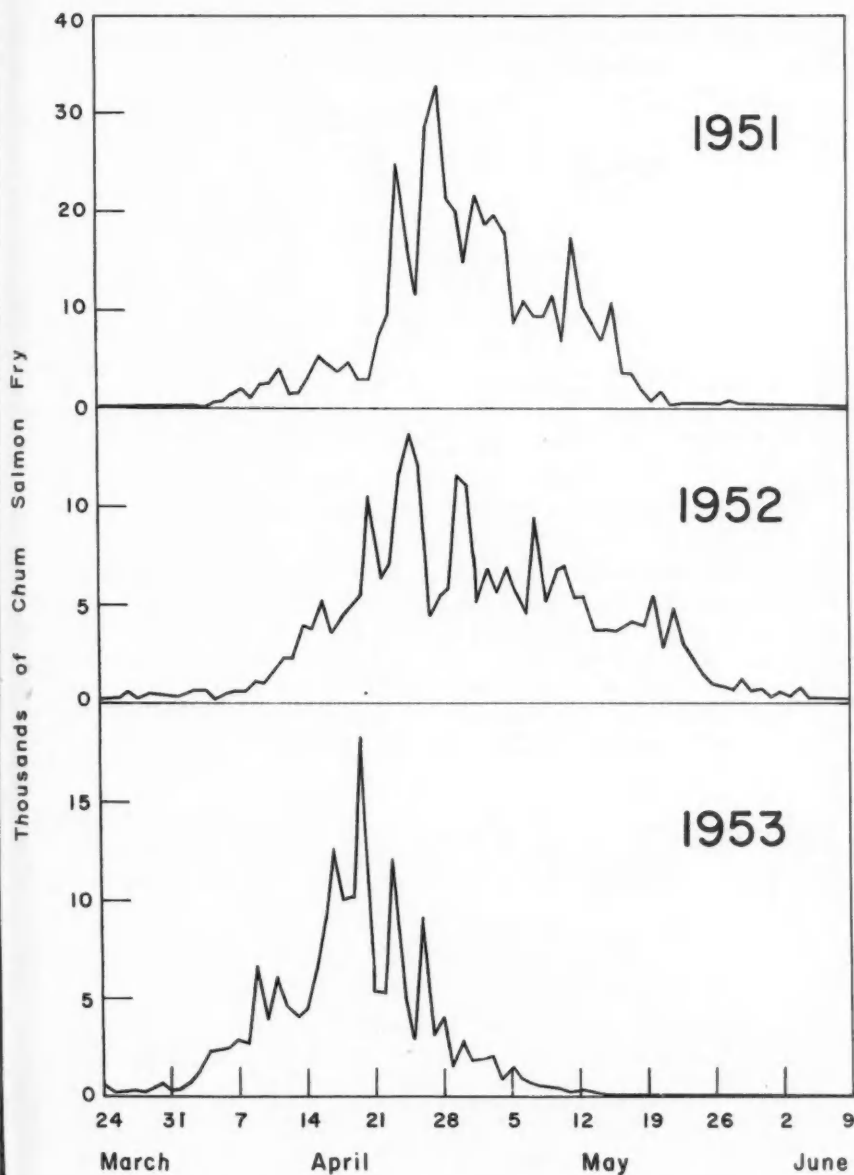


FIG. 7 (continued). Daily migration of chum salmon fry from Hooknose Creek.

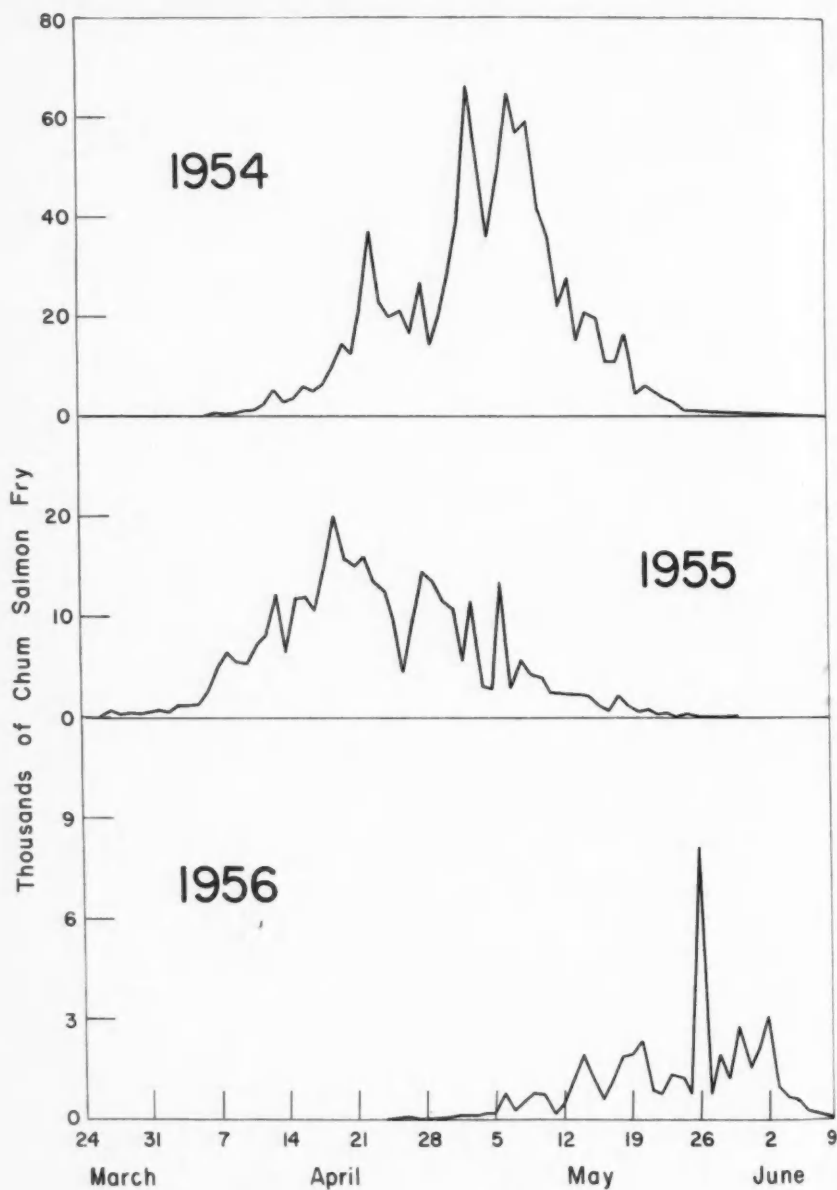


FIG. 7 (continued). Daily migration of chum salmon fry from Hooknose Creek.

The table shows a greater number of fry to be travelling near the surface of the water in the centre of the stream where water velocity was the greatest. Pink and chum fry had almost identical distribution in the stream.

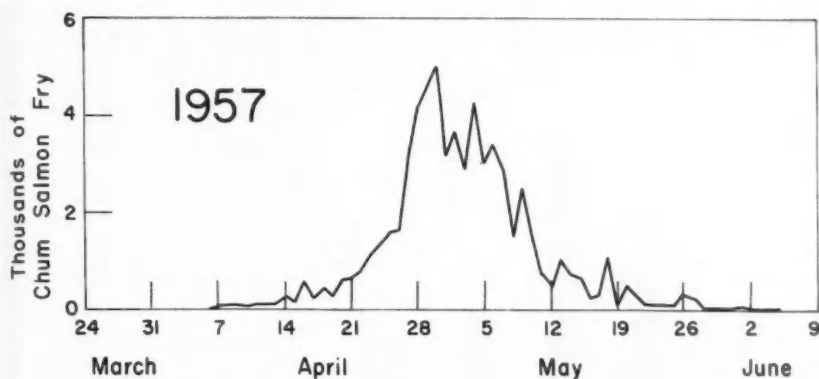


FIG. 7 (continued). Daily migration of chum salmon fry from Hooknose Creek.

In addition to the fyke net analysis of distribution the numbers of fry passing through different sections of the weir were also compared. The Hooknose Creek fry weir is divided into 14 sections. These 14 sections were subdivided into four groups for analysis. Four sections were allotted to each end group and three sections to each of the two centre groups. The numbers and relationship of fry per unit section of the four groups were counted and calculated to show the distribution of fry in the stream at the weir. This distribution relation is shown in Table X.

TABLE X. Ratio of pink and chum salmon fry per unit section of the four groups of sections in Hooknose Creek weir, as calculated from the combined egress of 1952 and 1953. Group 1, the 4 left-bank sections, was used as a standard.

	Group 1	Group 2	Group 3	Group 4
Pinks	1.00	1.85	1.93	1.53
Chums	1.00	1.63	1.68	1.37

The two centre groups of the weir capture more fry per section than do sections of either shoreward group. This is true for both pink and chum salmon fry. Although all sections carry equal quantities of water the two shoreward groups of sections have more eddy currents in front of them than do the two centre sections.

LENGTH OF FRESHWATER PHASE

It is not possible to give the exact mean incubation period for the pink and chum salmon eggs but an approximate measure for each of the years has been

arrived at by calculating the time elapsed from the 50% upstream adult migration point to the 50% point of the downstream migration of fry. The times recorded for pink and chum salmon in Hooknose Creek are shown in Table XI.

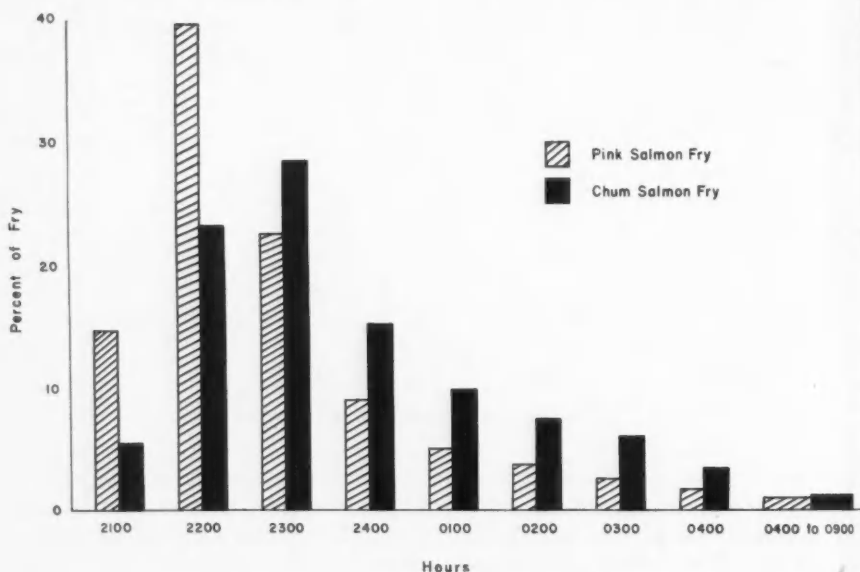


FIG. 8. Percentage of pink and chum salmon fry migrating downstream each hour in Hooknose Creek.

This tabulation shows that a fairly consistent period of time is required. Time of incubation will depend greatly on temperature. Pink and chum salmon have approximately the same period of time from 50% adult run to 50% fry run, though the chum salmon figures are more variable.

TABLE XI. Length of freshwater period of the life-cycle in Hooknose Creek.

Brood year	Pink salmon			Chum salmon		
	Date of 50% migration			Date of 50% migration		
	Adults	Fry	Total days	Adults	Fry	Total days
1947	September 20	April 18	210	October 10	May 6	208
1948	September 20	April 28	221	October 4	May 11	219
1949	September 20	April 28	220	October 8	May 13	217
1950	September 23	April 28	217	September 25	April 30	217
1951	September 27	April 26	211	October 3	April 30	210
1952	September 18	April 17	211	September 29	April 19	202
1953	September 19	April 30	223	September 30	May 5	206
1954	September 22	April 27	217	September 24	April 22	199
1955	September 22	May 7	228	October 2	May 26	237
1956	September 24	April 30	219	October 6	May 3	198

PREDATION

MORTALITY OF MARKED FRY

In 1951, on one day each week except for the week of peak pink and chum fry migration, 100 migrating chum fry were marked with coloured threads and released 300 yards upstream from the collecting weir the day following their first egress. Returns of marked fish showed losses occurred throughout the entire period of the migration and that these losses were greater at periods when fewer fry were migrating (Table XII).

TABLE XII. Mortality of marked chum fry in relation to total numbers of pink and chum fry migrating at Hooknose Creek, 1951.

Week ending	Number of fry migrants reaching weir	Percentage mortality of marked chums
April 7	4,976	66
14	20,188	41
21	46,741	33
28	224,696	—
May 5	218,970	44
12	95,921	55
19	48,178	70
26	3,271	85
June 2	1,539	71

The above table suggests that the mortality of marked chum fry is a result of predation; presumably the available predators become "saturated" with fry where the latter are most numerous. On two occasions thread-marked chum fry were recovered in predator stomachs. Difficulties attendant on recovery of marked chums were increased with increased numbers of migrating fry. Any oversight of marked fish when large numbers of fry were migrating would be interpreted as greater predation, yet percentage loss of fry decreased as the fry run increased in magnitude.

SPECIES OF PREDATORS

Hooknose Creek contains 6 species of fish which prey upon pink and chum salmon fry: coho salmon, dolly varden char, cutthroat trout, steelhead trout, Aleutian sculpin and prickly sculpin. Of these predators, coho salmon smolts, Aleutian sculpin and prickly sculpins are the most important because of their abundance. These three predators are also the only ones that make a regular and consistent migration through the weir. The numbers of all predators passing through the weir have been counted for all years under consideration.

POPULATION ESTIMATES OF SCULPINS

The ratio of Aleutian sculpin to prickly sculpin is 1:17 in Hooknose Creek (D. E. McAllister, personal communication). In view of similar behavior patterns

and size the two species have been combined for purposes of calculation of their numbers and their effects on pink and chum fry. These two sculpins spawn in the late spring and early summer in fresh water. They may spawn anywhere throughout the length of the stream but it has been found that large numbers migrate downstream to spawn in the intertidal region below the weir. In 1953 a population estimate of the numbers of sculpins in the stream was made. They were caught by angling, marked by the removal of pelvic fins and returned to the stream. Subsequent collecting by angling permitted calculation of an estimate of the population and confidence limits for it. Between June 15 and August 13 a total of 378 sculpins were marked. In the period September 2 to 7, 246 sculpins were caught of which 24 were marked. The best estimate of the population, using the method of Chapman (1948), was 3,874, with upper and lower 95% confidence limits of 5,765 and 2,447. These estimates were for sculpins of a size large enough to take salmon fry as food, that is, more than 5 cm in total length. The count of sculpins at the fry weir on Hooknose Creek in 1953 was 2,436 or approximately the lower limit of the estimate obtained from marking. Of the sculpins counted at the weir about 5% were too small to consume fry. However, the number of sculpins counted at the weir each year is undoubtedly less than the population actually present in the stream. The 1953 experiment suggests that the weir count was less than the total population by 37%. It is known from angling that all sculpins do not pass downstream to spawn. The total numbers of sculpins collected at the weir can be regarded as a minimum estimate of the true sculpin population, for the different years, of a length of 5 cm and over.

STOMACH CONTENTS OF SCULPINS

Analysis of stomach contents of sculpins during periods of salmon fry migrations indicates that the food consists almost exclusively of pink and chum salmon fry. The assumption is made that sculpins tend to consume constant absolute numbers of fry and that total consumption therefore does not vary much from year to year except in years of very low fry production. Neave (1953) has given a full account of the mechanics of this type of compensatory mortality.

The findings obtained by examining stomachs of sculpins that have been exposed to large concentrations of fry in weir traps are probably not representative of the general intensity of predation. Examination of such fish, however, does provide information on the capacity of sculpins of different sizes to take fry (Table XIII).

A total of 300 sculpins contained 649 fry giving an average of 2.16 fry per sculpin. This average of course is based on unequal and arbitrary numbers of the different size groups. Sculpins over 9 cm had consumed more than 2 fry.

Sampling sculpin populations for the purpose of stomach content analysis presents difficulties when specimens are taken during a salmon fry migration. Since the fry move at night, the sculpins must do their feeding at this period. When sculpins are collected in conjunction with a fry collecting weir there is the danger that they will be taken before they have completed their feeding. Samples of sculpins taken at Hooknose Creek were gathered during the course of the fry

TABLE XIII. Average numbers of pink and chum salmon fry present in the stomachs of sculpins of different total lengths in Hooknose Creek in 1951 and 1953.

Length class	Number of sculpins examined	Average number of fry per sculpin
<i>cm</i>		
3.1- 4.0	2	0.00
4.1- 5.0	4	0.00
5.1- 6.0	21	0.05
6.1- 7.0	39	0.67
7.1- 8.0	49	0.98
8.1- 9.0	49	1.31
9.1-10.0	54	2.07
10.1-11.0	27	4.19
11.1-12.0	28	4.54
12.1-13.0	14	5.71
13.1-14.0	14	5.57

migration but before the sculpins were among concentrations of fry in the pens. It is possible that some of these predators had not finished their feeding. A total of 88 sculpins were taken from April 11 to May 16 during the course of the 1953 and 1955 migrations. These sculpins, 10.3 ± 0.19 cm average length, consumed an average of 1.5 ± 0.30 fry per sculpin. The 246 sculpins caught in 1953 by angling had a mean length of 10.4 ± 0.15 cm. This was the group of fish upon which the population estimate was based.

Pritchard (1936) records that the average consumption of fry by sculpins in McClinton Creek for 1931 and 1933 was 0.8 and 1.5, and that these sculpins ranged from 4.4 to 17.8 cm long.

In attempting to estimate the quantitative effects of predation, it is important to have information both on the rate of feeding of the predators and their rate of digestion. It is not necessarily true that because a predator's stomach is empty the predator requires food. Also the time taken to digest food may not necessarily coincide with a one day period such as elapses between nightly fry migrations. J. G. McDonald (unpublished) found at Lakelse Lake, B.C. that coho smolts required between 40 and 50 hours to digest their food. The sculpin samples at both Hooknose Creek and McClinton Creek included many specimens with empty stomachs. In examining sculpin stomach contents at Hooknose Creek only those fry which had been consumed that night (within the preceding 4 hours) were counted, any partly digested fry remains being disregarded. Since only counts of recently eaten fry were made and since many sculpins had empty stomachs it was felt the resultant average measure of fry consumed per sculpin circumvented the problems of intermittent feeding and time required for digestion, so that the average established was a good estimate of the numbers of fry eaten per sculpin per day.

POPULATION OF COHO SMOLTS

Coho salmon smolts were counted as they passed through the weir on their seaward migration (Table XIV, below). In the Port John drainage system coho

smolts may live either in the lake or in the stream. Any smolts living in the lake would not be in contact with the emerging pink and chum fry populations in the stream except for a short period during their exit to the sea. In order to assess the proportion of the population of coho smolts that might be lake dwellers a trap was operated in the stream at the lake outlet in 1950. This trap covered half the width of the stream and was operated through the major part of the pink and chum fry escapement period and after until the coho smolt migration was complete. No smolts were captured during the entire period of the operation of the traps. It was concluded the entire population of coho smolts were living in the stream and were feeding upon pink and chum salmon fry.

STOMACH CONTENTS OF COHO SMOLTS

The problems of sampling coho salmon smolts for stomach contents are essentially the same as those for sculpins. At Hooknose Creek a sample of 16 coho smolts taken from pens containing pink and chum salmon fry yielded an average content of 4.3 ± 0.6 fry per coho smolt. Pritchard (1936) reports for a sample of 365 coho smolts an average consumption of 2.7 fry per smolt in 1931 and 3.7 fry per smolt from 20 samples examined in 1933. Although Pritchard's smolts were not taken from such unrepresentative conditions as artificial concentrations of fry in pens they were captured from in front of the weir where a certain concentration of the migrating fry did exist.

J. G. McDonald (unpublished) examined stomach contents of coho smolts moving downstream in Scully Creek, Lakelse Lake, B.C., before the nightly fry migration had commenced. He found that these fish had not fed recently (that night) but had identifiable remains of fry in their stomachs from the night previous. In all, 42 smolts were examined between May 21 and June 2 in 1954 and were found to contain an average of 2.0 fry per smolt. Some of these smolts showed completely empty stomachs. Again, as with sculpins, this average is felt to be a good estimate of daily fry consumption considering the vagaries of rate of feeding and digestion. The data from Hooknose Creek and McClinton Creek (Pritchard, 1936) show higher fry consumption by smolts than the Scully Creek data. In the latter instance, however, the smolts were not exposed to artificially high concentrations of fry as they were at Hooknose Creek and McClinton Creek.

By assuming a daily consumption rate by sculpins and coho smolts of 1.5 and 2.0 fry respectively, and by knowing the abundance of these predators, a calculation of the total extent of predation by these two species can be made.

CALCULATION OF PREDATION

Calculations of predation can be simplified by converting these two rates of predation to a single rate. If we use the rate of predation by sculpins (1.5 fry/day) as our unit rate then coho smolts since they consumed 2.0 fry/day are equivalent to 1.33 sculpins. The number of coho smolts converted into sculpin predation units and the sculpins in Hooknose Creek for years 1948 to 1956 are shown in Table XIV.

The pink and chum fry migration lasts over a period of more than 60 days but significant numbers are restricted to a period of approximately 50 days. The predatory sculpins and coho smolts also move downstream past the weir but their migratory season lags behind that of the salmon fry. About 70 to 80% of these

TABLE XIV. Number of coho smolts counted and converted to "predation units" by multiplying by the constant 1.34, number of sculpins counted and the total number of predation units in Hooknose Creek.

Year	Coho smolts counted	Coho predation units	Sculpins counted	Total units of predation
1948	7,959	10,665	5,273	15,938
1949	3,550	4,757	1,974	6,731
1950	2,982	3,996	1,407	5,403
1951	4,389	5,881	3,293	9,174
1952	3,620	4,851	3,552	8,403
1953	4,043	5,406	2,436	7,842
1954	5,987	8,023	2,312	10,335
1955	6,756	9,053	3,601	12,654
1956	4,508	6,041	3,062	9,103
1957	6,074	8,139	2,640	10,779

predators are present above the weir during the fry migration. This relationship between fry migration and predator migration can be seen in Fig. 9. Assuming the minimum percentage of 70% effectiveness of the predators for a period of 50 days an equivalent period of time for 100% effectiveness is found to be 35 days.

Predation is then calculated on the assumption that the total predator units consume fry at the rate of 1.5 fry/day for a period 35 days. On this basis the estimated minimum numbers of fry consumed by predators for the years 1948 to 1957 are shown in Table XV.

Minimum figures for calculating the amount of predation have been used throughout. Actual predation is probably higher since other stocks of predacious fish present in the stream are not considered in these figures. Limited predation also results from piscivorous birds such as kingfishers and mergansers. Mink were

TABLE XV. Estimated numbers of pink and chum salmon fry consumed by sculpin and coho smolts in Hooknose Creek.

Year	Number of fry consumed
1948	836,745
1949	353,377
1950	283,657
1951	481,635
1952	441,157
1953	411,705
1954	542,587
1955	664,335
1956	477,908
1957	565,898

sometimes found raiding collecting pens and it was noted that they had preyed on sculpins. In these cases, although measures were taken to prevent further losses, the numbers of sculpins were not known and were omitted from the counts.

PINK AND CHUM FRY ESCAPEMENT

The survival of pink and chum salmon eggs to migrating fry varied considerably during the period of study as is shown in Table XVI.

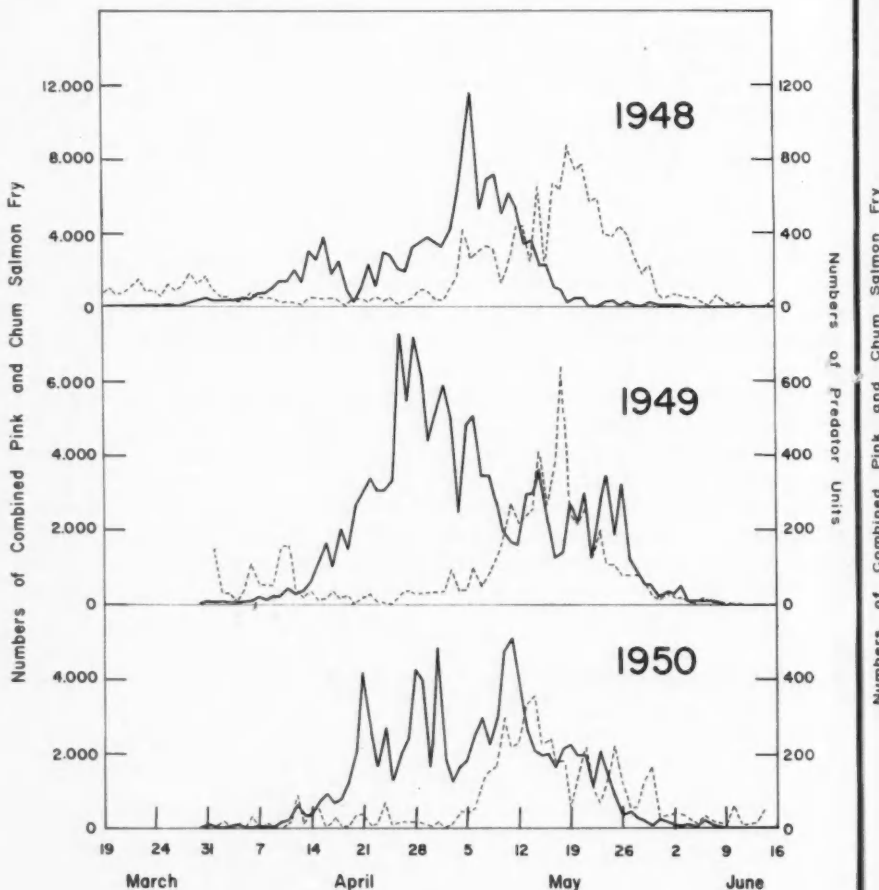


FIG. 9. Daily downstream migration of combined pink and chum salmon fry (solid line) and "predator units" (broken line) in Hooknose Creek.

The range of variation in egg to fry survival for pink salmon is $16.47/0.88 = 18.72$ and for chum salmon is $19.41/0.99 = 19.61$. Simply stated, survival can be 18.7 times as great as the lowest recorded survival for pink salmon and 19.6 times as great for chum salmon. Variations in survival of this magnitude can easily account for good returns from a poor spawning escapement and conversely for poor returns from good escapements.

PINK AND CHUM SALMON FRY EMERGENCE

The difference between fry escapement and fry emergence is principally a result of consumption of fry by predators (Table XVII).

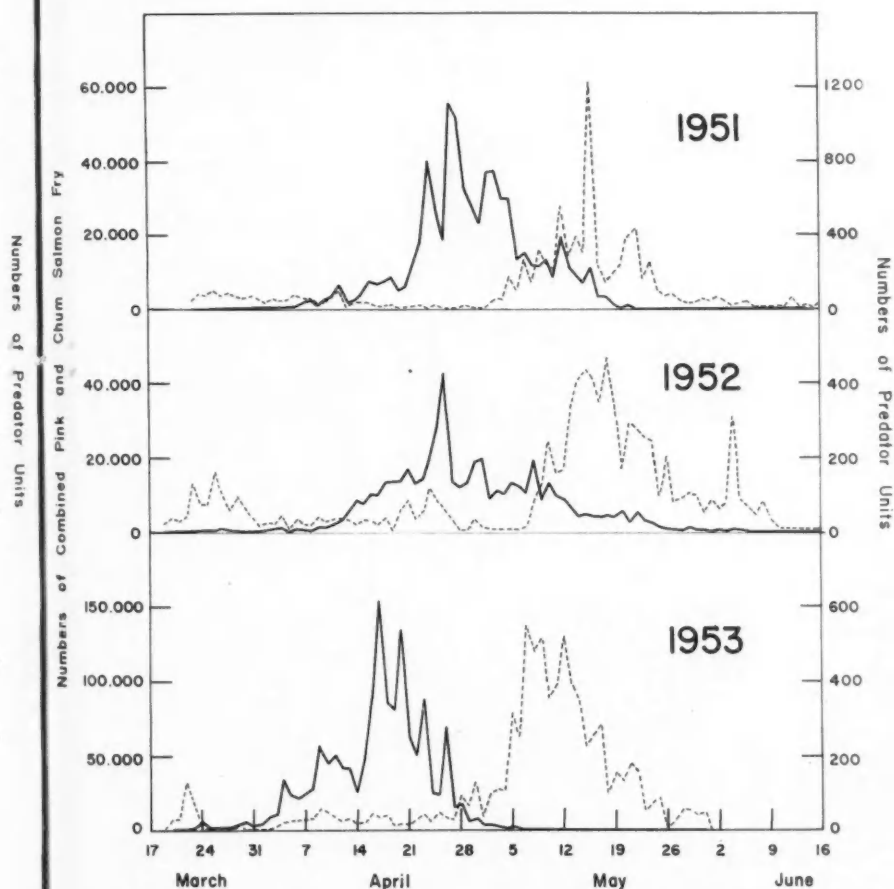


FIG. 9 (continued). Daily downstream migration of combined pink and chum salmon fry (solid line) and "predator units" (broken line) in Hooknose Creek.

The range of variation in survival from egg to emerging fry is $31.08/5.70 = 5.45$. Thus even when predation is removed or reduced to insignificant figures, as happens in years of large escapements such as 1954, the highest survival is 5.5 times the lowest recorded.

PREDATOR EFFECT ON SURVIVAL IN THE FRESHWATER STAGE

Predation from year to year tends to be constant and even when large populations of fry are available the predators do not take significantly more. In years when the population of fry is small the predators may experience difficulty in satiating themselves and the actual consumption of fry will be less. Fluctuations

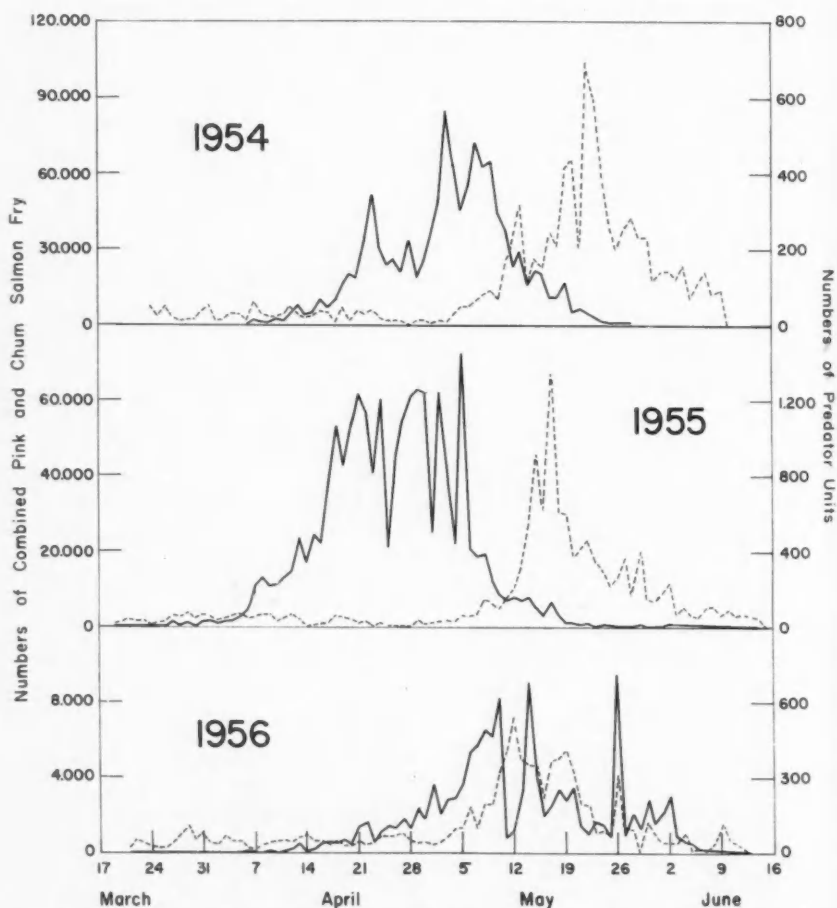


FIG. 9 (continued). Daily downstream migration of combined pink and chum salmon fry (solid line) and "predator units" (broken line) in Hooknose Creek.

TABLE XVI. Numbers of eggs deposited, fry counted, and percentage survival of eggs to fry for both pink and chum salmon in Hooknose Creek.

Brood year	Pink salmon			Chum salmon			Combined percentage survival
	Potential deposition of eggs	Numbers of fry counted	Percentage survival	Potential deposition of eggs	Numbers of fry counted	Percentage survival	
1947	3,788,764	33,349	0.88	10,977,470	108,746	0.99	0.96
1948	787,167	64,312	8.17	1,054,702	77,539	7.35	7.70
1949	838,200	54,061	6.45	714,469	44,463	6.22	6.34
1950	1,550,715	234,396	15.12	2,858,128	431,399	15.09	15.10
1951	1,475,712	242,993	16.47	1,593,524	269,701	16.92	16.71
1952	8,510,908	1,227,025	14.42	938,463	182,200	19.41	14.91
1953	1,464,672	204,250	13.95	6,016,495	984,504	16.36	15.89
1954	28,200,382	907,458	3.22	5,580,784	353,761	6.34	3.73
1955	1,275,768	86,256	6.76	1,275,960	49,443	3.87	5.32
1956	14,470,935	454,148	3.14	3,804,673	69,830	1.84	2.87
All years	62,363,223	3,508,248	5.63	34,814,678	2,571,586	7.39	6.26

TABLE XVII. Numbers of pink and chum salmon fry counted through weir, calculated numbers of salmon fry eaten by sculpin and coho smolts, total fry emergence, potential egg deposition and the percentage survival of eggs to emerging fry.

Brood year	Enumerated salmon fry		Numbers of fry eaten by predators	Total fry emergence	Potential egg deposition	Percentage survival of eggs to emergence
	Pinks	Chum				
1947	33,349	108,746	836,745	978,840	14,766,000	6.63
1948	64,312	77,539	353,377	495,228	1,842,000	26.89
1949	54,061	44,463	283,657	382,181	1,553,000	24.61
1950	234,396	431,399	481,635	1,147,430	4,409,000	26.02
1951	242,993	269,701	441,157	953,851	3,069,000	31.08
1952	1,227,025	182,200	411,705	1,820,930	9,449,000	19.27
1953	204,250	984,504	542,587	1,731,341	7,481,000	23.14
1954	907,458	353,761	665,335	1,925,554	33,781,000	5.70
1955	86,256	49,443	477,908	613,607	2,552,000	24.04
1956	454,148	69,830	565,898	1,089,856	18,276,000	5.96

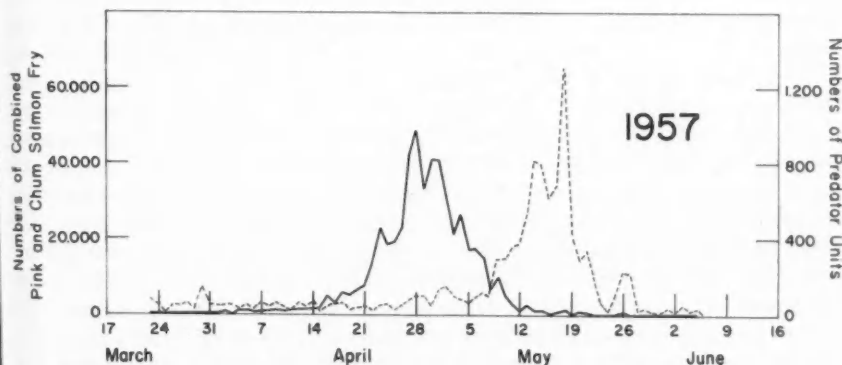


Fig. 9 (continued). Daily downstream migration of combined pink and chum salmon fry (solid line) and "predator units" (broken line) in Hooknose Creek.

in abundance of predators changes the amount of predation. In Table XVIII the fry emergence, the fry predation and the percentage predation are shown.

The table below clearly indicates the magnitude of importance which predators may assume. This is particularly so in years of low fry production when as much as 85% of the fry population is removed by predator activity.

A reduction of the sculpin population by 80% in Hooknose Creek would effect, on the average, a saving of 125,000 fry each year.

TABLE XVIII. Pink and chum salmon fry emergence, predation and percentage predation in Hooknose Creek.

Brood year	Pink and chum fry emergence	Numbers of fry eaten by predators	Per cent predation
1947	978,840	836,745	85.48
1948	495,228	353,377	71.36
1949	382,181	283,657	74.22
1950	1,147,430	481,635	41.98
1951	935,851	441,157	46.25
1952	1,820,930	411,705	22.61
1953	1,731,341	542,587	31.34
1954	1,925,554	664,335	34.50
1955	613,607	477,908	77.89
1956	1,089,876	565,898	51.92
Total	11,138,838	5,059,004	45.42

INFLUENCE OF VARIOUS FACTORS ON SURVIVAL TO FRY EMERGENCE

SEX RATIO

The sex ratios of spawning pink and chum salmon in Hooknose Creek are shown in Table II. No significant correlation was found between percentage emergence of fry and sex ratio of the spawning fish. Sex proportions of pink and chum salmon spawning in Hooknose Creek do not differ greatly from a 1:1 ratio and even if greater discrepancies had been found, a significant correlation between survival and sex ratio would not have been expected in view of findings reported elsewhere. Hobbs (1937) reports that male quinnat salmon (*Oncorhynchus tshawytscha*) spawn with more than one female. M. P. Shepard (unpublished) found both male pink and chum salmon in Hooknose Creek will spawn with more than one female. A report of work carried out by the Fisheries Research Institute of the University of Washington (Pacific Fisherman, April, 1950) suggests that sex ratio discrepancies as great as 1 male to 15 females can exist without any appreciable mortality of eggs. Observations subsequent to those of Shepard at Hooknose Creek confirm his observations that multiple spawning of male pink and chum salmon occurs. Under these conditions it would be expected that survival efficiency of the potential deposition of eggs would not be altered by sex ratios unless vastly different from a 1:1 ratio.

WATER DISCHARGE

Water discharge of the creek, particularly during spawning and early developmental stages, could affect survival in many ways. Accessibility of spawning locations, extent of superimposition of redds, erosion, silting and subsurface volume of water flow carrying dissolved gases could all vary with the stream discharge. Correlation of percentage survival of fry to emergence with the September and October stream discharge failed to show a significant relationship. High water levels during spawning created greater fringe area spawning. Lower water levels during the winter left much of this fringe area exposed to freezing and desiccation.

TEMPERATURE

Temperature may either directly or indirectly, through viscosity or dissolved gases, affect the survival of eggs. Calculations using the mean September and October water temperatures at Hooknose Creek failed to produce a significant relationship with percentage survival of emergent fry within the ranges of temperature recorded. Similarly correlation between percentage emergent survival and incubation time, which is in part a measure of temperature, showed no significant relation.

DENSITY OF SPAWNING PINK AND CHUM SALMON

In the material considered to date the major factor showing a relationship with emergent survival of fry has been the varying numbers of pink and chum salmon spawning in the stream.

Density of spawners, or of eggs deposited, may affect success of hatch in various ways. It has an influence upon conditions affecting the eggs in the gravel, which would include amount of subsurface water flow, amount of dissolved oxygen carried to the eggs, carbon dioxide and nitrogenous wastes removed from the eggs, superimposition of redds, and other lesser factors.

The inverse relation between the number of eggs deposited and the percentage survival of eggs to emerging fry is shown in Table XVII and Fig. 10. The latter also shows the relationship between survival and density of eggs per square yard of spawning gravel.

As stated previously, population density affects the supply of things required by the developing eggs. A point must be reached, with increasing deposition of eggs, where the supply of the requirement for at least some of the eggs is seriously reduced and the right hand side of the production curve (Fig. 11) begins to descend, that is, overseeding of the spawning beds is taking place.

In the two years, 1947 and 1956, when deposition was moderately high—15 and 18 million eggs, respectively—the resulting low production of fry cannot be explained on the basis of the current year's deposition alone. However, eggs lying in the gravel, whether dead or alive, require oxygen and give off waste products. In years of heavy deposition only a small percentage of the eggs survive and emerge, leaving a great burden of dead eggs in the gravel which continue to utilize a proportion of the available oxygen. It is known from sampling in the

stream bottom of Hooknose Creek that these dead eggs are still present and decaying up to two years later. On this basis, it might be expected that deposition for the next two years after a really large run would show lower survival rates than expected, since in reality the oxygen demand of the dead and live mass of eggs in the gravel of the second and third year might be greater than the first.

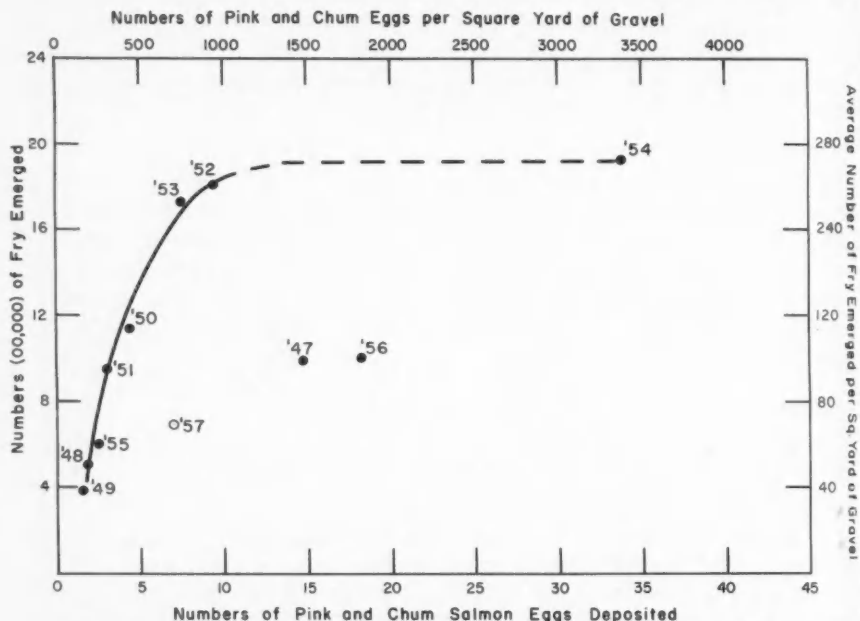


FIG. 10. Inverse relation between numbers of pink and chum salmon eggs deposited (in millions) and percentage survival of eggs to emergent fry in Hooknose Creek, for spawning years 1947-57. (1 sq yard = 0.84 sq metre.)

Accurate records of egg deposition previous to 1947 are lacking but it is known that the 1945 pink salmon run was a large one. Carry-over of dead eggs from this cycle would help to depress the survival from the 1947 egg deposition. Similarly, the 1955 and particularly the 1956 survival of emergent fry is depressed below the expected survival, following the extremely heavy egg deposition in 1954 (Fig. 11). (The small number of eggs deposited in 1955, and the relatively large contribution that the estimate of consumed fry makes to the estimate of fry emerged, results in a very uncertain estimate of that emergence—however, it lies below the trend line.)³

³Since this paper was prepared, the data from the 1957 brood year has become available. A deposition of 6,980,000 pink and chum salmon eggs in Hooknose Creek produced 196,000 fry. Assuming an average predation of 500,000 fry, and adding it to the numbers of fry counted, results in an estimated emergence of 696,000 pink and chum salmon fry showing a percentage emergence of 9.97%. This point has been added to Fig. 10 and 11. The 1956 egg deposition was the second largest recorded, and dead eggs left from it would decrease the survival of the 1957 stock below normal expectation.

Freehand lines have been drawn through the different points in Fig. 10 and 11 to better show the suggested relationship for normal years (1947, 1956 and 1957 were not considered). Even apart from these latter years, irregularities are evident, particularly in Fig. 10; but these occur in instances when the deposition of eggs has been low, so that any error in estimating the number of fry taken by predators plays a large role.

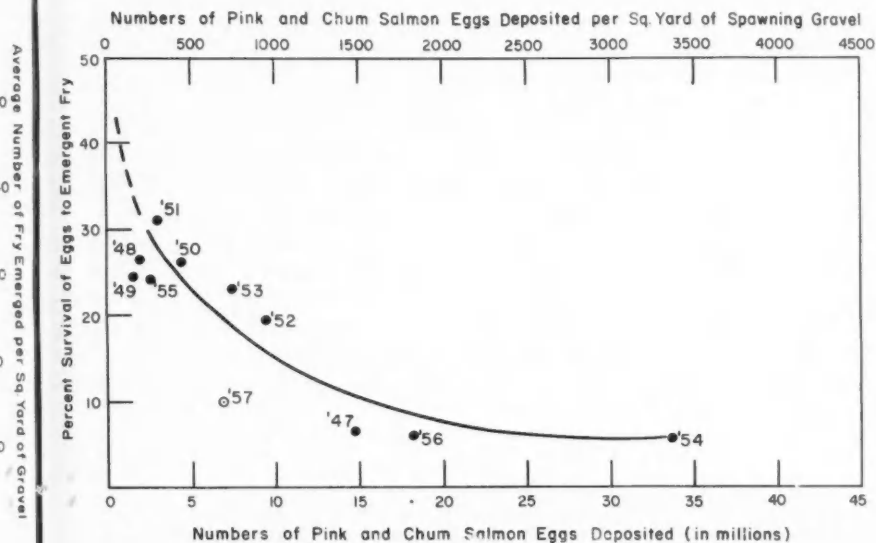


FIG. 11. Relation between numbers of pink and chum salmon eggs deposited and resultant numbers of emergent fry in Hooknose Creek, for spawning years 1947-57.

In general, increased fry emergence results from increased deposition of eggs; that is, more spawning fish produce more progeny, up to a limit at about 280 fry per square yard (330 per sq m), provided there has been no heavy deposition during the previous 2 years. Also, when greater numbers of fry are produced, the *relative* contribution of predation to fry mortality is reduced (Table XVIII), so that fry escapement to the sea is greatly improved. This "depensatory" effect of stream predation has been discussed by Neave (1956).

More detailed information on subsurface water flow and biological oxygen depletion is required to explain fully the reduced fry emergence which has been found in year-classes following one with a big egg deposition.

Among pink salmon, one cycle is usually dominant, although this dominance may change cycles occasionally. A preceding year of heavy egg deposition may be a factor in suppressing the success of the succeeding year, thus helping to keep low a run that is already low. However, effects that last to the *second* year following a big run, such as are suggested above, tend to depress the original big year itself.

Thus any role of delayed egg decomposition in initiating or maintaining cycle dominance in Hooknose Creek pinks could not be simple, though it may exist. For sockeye having a 4-year life cycle, heavy spawning in one year might, in some situations, affect the spawning grounds for 2 or even 3 years subsequently, and so contribute to the dominance of a single cycle such as is observed in some sockeye stocks. Similarly, heavy deposition of eggs of sockeye salmon in a dominant year may biologically affect the spawning grounds in succeeding years, so that dominance of any one cycle may persist for long periods of time.

OCEAN SURVIVAL

Since pink salmon have a precise two-year life cycle, a count of the adults returning from the fry escapement of the year previous provides an easy measure of their survival in the sea. Chum salmon, because of their different ages at maturity, present a more difficult problem of ocean survival assessment.

In the spring of 1948 pink and chum salmon fry were marked by the removal of the two pelvic fins. Since pink salmon maintain a definite two-year cycle the marked adult salmon returning from these marked fry releases provided a basis for determining the losses resulting from marking. This percentage loss by marking was applied to chum salmon so that from the return of marked adult chum salmon it was possible to calculate the survival of chum salmon in the sea. Figures obtained are shown in Table XIX.

TABLE XIX. Numbers of marked and unmarked 1947 brood year pink and chum salmon fry released, returned to Hooknose Creek as adults and percentage ocean survival after fishing mortality. (Marking mortality for chums is estimated as equal to that for pinks.)

Species	Pink salmon	Chum salmon
Numbers of marked fry released	10,787	54,831
Numbers of marked adults returned	103	259
Numbers of unmarked fry released	20,516	44,888
Numbers of unmarked adults returned	1,070	...
Mortality resulting from marking	81.68%	(81.68%)
Calculated return of marked fish from marked fry if no marking mortality occurred	563	1,414
Survival in the ocean	5.22%	2.58%

Observations show that chum fry return as adults at different ages. Fry marked at Hooknose Creek in 1948 returned as 3, 4 and 5 year old fish in the respective percentages of 19.7, 71.8 and 8.5. Scale samples from 397 chum salmon caught by the commercial fishery in the vicinity of Hooknose Creek in 1948 showed the age composition of that year to be composed of 3, 4 and 5 year old fish in the respective proportions of 10.3, 85.2 and 4.5 per cent.

Since different year-classes of chum salmon are of different numerical strength, the proportions of the age groups which are present will vary from year to year. This fact makes it difficult to measure the ocean survival in terms of adults returning from known fry escapements. However, by summing several years' escapement of fry and return of adults, a weighted mean ocean survival has been calculated for chum salmon in Table XX.

TABLE XX. Numbers of chum salmon fry released, numbers of adult chum salmon returned 4 years after these releases, and resultant weighted mean ocean survival for the period.

Brood year	Number of fry released	Number of adults returned 4 years later
1947	108,746	1,329 ^a
1948	77,539	871
1949	44,463	4,335
1950	431,399	3,336
1951	269,701	1,219
1952	182,200	3,131
1953	984,504	3,698 ^b
Total	2,098,552	17,919
Weighted mean ocean survival		0.85%

^a5-year-old fish of the 1946 year-class included and 3-year-old fish of the 1947 year-class not included.

^b3-year-old fish of the 1954 year-class included and 5-year-old fish of the 1952 year-class not included.

Similarly, a weighted mean ocean survival for pink salmon has been calculated from the known fry escapements and number of adults returning (Table XXI). Ocean survival of pink and chum salmon for individual years is shown in Table XXII. This survival is after both natural and fishing mortality have occurred.

TABLE XXI. Numbers of pink salmon fry released, numbers of adult pink salmon returned two years after these releases and resultant weighted mean ocean survival for the period.

Brood year	Numbers of fry counted	Numbers of fry released	Number of adults returned 2 years later	Percentage return
1947	33,349	20,516 ^a	1,070 ^a	
1948	64,312	60,841	1,857	2.89
1949	54,061	52,399	1,670	3.09
1950	234,396	232,636	8,685	3.71
1951	242,993	237,963	1,599	0.66
1952	1,227,025	1,212,798	31,402	2.56
1953	204,250	199,966	1,310	0.64
1954	907,458	898,481	21,650	2.38
1955	86,256	85,737	2,333	2.71
Total	3,054,100		71,679	
Weighted mean ocean survival				2.35%

^aDoes not include marked fish.

TABLE XXII. Marine survival for pink and chum salmon in Hooknose Creek.

Brood year	Marine survival of fry to adults after natural and fishing mortality	
	Pink salmon	Chum salmon
1947	5.2	2.6
1948	3.1	
1949	3.2	
1950	3.7	
1951	0.7	
1952	2.6	
1953	0.7	
1954	2.4	
1955	2.7	

Greater age before maturity exposes the chum salmon to the causes of natural mortality for a longer period of time than the pink salmon. Differences in fishing intensity may also in part be responsible for differences of survival of the two species. However, the large difference between the estimates of pink and chum salmon ocean survival is also partly accounted for by the smaller number of years' observations for chum salmon. The single brood year from which a large number of chum salmon fry were released was also the brood year of pink salmon which resulted in one of the lowest ocean survivals recorded. The large numbers of chum fry released in this year with the resulting low survival has, in view of the few samples years, weighted the mean ocean survival unduly.

Marine survival varies, although it varies less than the freshwater survival, its range is considerable. Variation of the marine survival of pink salmon is $5.2/0.7 = 7.4$ times the lowest survival. This marine survival, however, is based on the return of adults to the spawning stream and does not account for the different intensities of the commercial fishery that exist from year to year. Assuming that pink salmon from Hooknose Creek experience the same fishing intensity as the pink salmon from the statistical area in which Hooknose Creek lies, then a correction of the marine survival based upon yearly fluctuations of fishing pressure is possible. Stream escapement and commercial catch records gathered and reported by the Department of Fisheries indicate the percentage

TABLE XXIII. Percentage spawning escapement of pink salmon run in area 8, Hooknose Creek pink salmon marine survival and calculated Hooknose Creek pink salmon marine survival if no commercial fishing operating for the brood years 1949 to 1955.

Brood year	Area 8 spawning escapement	Observed marine survival (including effect of fishing)	Calculated marine survival (excluding effect of fishing)
	%	%	%
1949	28.5	3.2	10.8
1950	45.0	3.7	8.2
1951	45.0	0.7	1.4
1952	29.0	2.6	8.7
1953	62.7	0.7	1.0
1954	38.5	2.4	6.2
1955	62.3	2.7	4.3
Weighted mean ocean survival		2.4	6.7

of the streams of the area to spawn. This percentage, the marine survival calculated from the pink salmon entering Hooknose Creek, and the corrected marine survival of pink salmon entering Hooknose Creek if no commercial fishery were operative, are shown in Table XXIII.

Variation of the marine survival for pink salmon in the area before fishing took place amounted to $10.8/1.0 = 10.8$. The average marine survival of 6.7% for pink salmon is still 6.7 times as great as the lowest recorded survival. A factor as large as this is enough to reduce or increase a moderate escapement of fry to either a low or high return of adults.

PREDICTION

Pink and chum salmon survival in Hooknose Creek has been considered in the main to be dependent upon the density of eggs deposited in the gravel. Eggs deposited in previous years and which failed to live may still be present and must be considered as a part of the deposition since they continue to use up oxygen carried by the water. Information is as yet insufficient to predict fry survival for years of heavy egg depositions and for years following heavy egg depositions. However, at low or medium levels of egg deposition, provided they do not follow closely a year of very high deposition, prediction of fry is possible. Floods and droughts, as well as other unrecognized conditions, probably affect survival but such factors were of minor importance at Hooknose Creek during the years of this study.

The value of selecting a single small stream and applying the results obtained to a wider area is limited. The porosity or amount of water flow through the spawning gravel is important in determining survival but the major fluctuations in survival of any stream are brought about by the fish themselves. Therefore predictions, from a single stream, of the number of fry produced over a large area cannot be considered to be very accurate.

Marine survival has been shown to fluctuate, although the conditions which cause this fluctuation are not known. A calculated average survival provides a statistical basis for predicting adult returns but biological reasoning for such returns is lacking. Ocean mortality is not considered to be compensatory, that is, it is not dependent upon the numbers of fry in the sea. Quite frequently large catches of fish, undoubtedly the survivors of large fry escapements, have continued in an area for many years and then suddenly a sustained crash in the fishery has occurred. In these instances mortality in fresh water may play an important role, yet the crashes are within the order of size of the range of marine survival fluctuations. Examples of low ocean survival of Hooknose Creek fish in certain years have already been shown. Further support of the view that ocean mortality is density independent is given by Murphy and Shapovalov (1951) in their analysis of northern California salmon and steelhead runs. As yet the best predictions of ocean survival are those arrived at by an average of survival past years. Limits of success of such a prediction can be calculated as more years' data becomes available.

SUMMARY AND CONCLUSIONS

This study was begun at Hooknose Creek in 1947 and embraces the results of the period from the fall of 1947 to the spring of 1957. Physical conditions in the stream and meteorological records have been kept and all species of fish passing through the weirs have been counted.

The numbers of adult pink salmon ranged from 1,160 to 31,402 and chum salmon adults from 718 to 10,191 fish. Sex ratios of these fish did not vary greatly from 1:1. The females of the two species were sampled each year for egg content. Calculations of egg deposition were made each year from mean egg content and numbers of spawning female fish. The combined egg deposition of pink and chum salmon ranged from 1,552,000 to 33,782,000 eggs.

Spawning occurred throughout a major portion of the stream and in approximately the same proportions in each area each year.

Redd sampling in Hooknose Creek showed, particularly in the years of heavy egg depositions, that mortality occurred chiefly before the "eyed" stage of egg development was reached.

Combined pink and chum fry counts ranged between 99,000 and 1,409,000 fry from the egg depositions during the 10 years of study.

Survival from eggs to migrating pink and chum fry ranged from 0.88% to 19.41%.

Predation on the emerging fry by the two most abundant predators, coho salmon smolts and sculpins, amounted to a loss of approximately 500,000 fry each year. Making allowance for this predation, emergence of fry from the gravel is estimated to have ranged from 382,181 to 1,925,524 fry and the per cent survival of eggs to emerging fry from 5.70% to 31.08%.

Variations in survival from eggs-in-females to fry at emergence from the gravel are inversely and rather closely related to the number of spawning adults. Effects of stream discharge, temperature and other factors, though doubtless present, could not be demonstrated from available data.

The average ocean survival was 2.35% for pink salmon and 0.85% for chum salmon, weighted by size of the escapement; these figures include effects of the fishery.

Prediction of numbers of fry produced from known seedings is not possible, except for light to medium seedings which follow light to medium seedings. More information regarding heavy seedings and past heavy seedings is necessary for accurate predictions. Results from Hooknose Creek do not necessarily provide an accurate indication of survival and production in other streams in the area. Prediction of adult salmon returns from known fry escapements can as yet be made only from average figures; variations in survival in the sea have yet to be taken into account.

Production of pink and chum salmon can be increased by the removal of predators. In many cases the removal of sculpins alone would allow enough fry to escape to offer good prospects of a sustained increase in the level of production. At the present time, low runs tend to be kept in this condition by the action of predators.

The variation in survival from egg to migrating fry can be considerable, as can be the survival of migrant fry to adult salmon. A combination of these two survival rates theoretically can make possible a range of 1 to 190 times the size of a resultant run of fish from a given egg deposition.

Overseeding streams will lower production only slightly in comparison to the low production caused by underseeding a region.

ACKNOWLEDGMENTS

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Phosphorus Enrichment of Drainage Waters from Farm Lands¹

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ABSTRACT

Excellent production of brook trout (*Salvelinus fontinalis*) and drainage from a stabilized agricultural area are associated in the streams and ponds of Prince Edward Island. Determinations of phosphorus content of Ellerslie Brook, P.E.I., showed major contributions from commercial fertilizers applied to cultivated land. The inference appears valid that commercial land fertilizers are an important factor in maintaining high trout production, and may enhance oyster production in shallow saltwater inlets at the mouths of the streams.

INTRODUCTION

THE DEVELOPMENT of farm lands alters the quality and flow patterns of drainage waters. Greater extremes in water level and temperature, and increased silting of streams almost invariably result from attempts to cultivate marginal land, and from poor farm practices even on good soils (Richardson, 1944). The changes are frequently detrimental to indigenous fish life. On the other hand, adverse effects are minimized where soil character stimulates good husbandry. The adverse effects may be substantially offset, for instance, by an increased fertility of the waters arising from organic and inorganic fertilizers applied to land.

Prince Edward Island is a stabilized farming community. Approximately 50% of the area of the province consists of improved farm lands (Canada Year Book, 1957-58). Because of the small area of the Island (2,184 sq mi; 5,657 sq km), drainage is largely by small, spring-fed streams. These, and ponds formed on them, are highly productive of brook trout, *Salvelinus fontinalis* (Smith, 1951). Data submitted in this article on the phosphorus content of the water of Ellerslie Brook, P.E.I., support the view that fertilizers applied to farm lands contribute materially to the fertility of Island streams and ponds, and to their trout-producing capacities. The data were obtained during a study of the population and movements of brook trout at Ellerslie Brook (Smith and Saunders, 1958).

AMOUNTS OF COMMERCIAL FERTILIZERS APPLIED TO PRINCE EDWARD ISLAND FARMS

In recent years about 50,000 tons (1 ton = 907.18 kg) of commercial fertilizers of various formulae have been applied annually to Prince Edward Island farms. The amounts sold to Island farmers in 1955, 1956 and 1958 were 48,993, 48,888 and 53,034 tons respectively (B. G. Rogers, P.E.I. Department of Industry and Natural Resources). Most of the fertilizer is applied to potato fields. In 1955 and 1956, 87 and 88% of the fertilizers sold to farmers consisted of potato mixtures.

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We are more particularly concerned with the amounts of commercial fertilizers added to the Ellerslie Brook watershed. The following amounts are known to have been applied to cultivated land (almost entirely potato fields) on that watershed in the years 1948-50. This information was obtained by contact with the farmers of the area. (The fertilizer formula, 4-8-10, signifies that by weight there is 4% nitrogen as N, 8% phosphorus as P_2O_5 , and 10% potassium as K_2O .)

	Ton	Fertilizer formula	Phosphorus as P	
			lb	kg
1948	62	4- 8-10	4,679	2,122
1949	32½	4- 8-10		
	18	4- 8-13	3,527	1,600
1950	21	4- 8-10		
	4	5- 8-13		
	2½	5-10-13		
	1½	5-10-10		
	¼	4- 8-13	2,112	958

ELLERSLIE BROOK DRAINAGE AREA

Ellerslie Brook and its trout population have been described by Smith and Saunders (1958). The stream at low-water summer levels has a length of about 6 mi (10 km), and drains approximately 10 sq mi (26 sq km). In the years 1948-50, about 1,800 acres (730 ha) of the drainage area were under cultivation. The remainder of the area consisted of pasture lands and woodlots.

The underlying rock formation of Prince Edward Island is, for the most part, Permo-Carboniferous sandstone. "Prince Edward Island lies in the Podzol Soil Zone, i.e., in a region in which Podzols are the dominant group of well and moderately well-drained soils" (Whiteside, 1950).

In the Ellerslie drainage area, top soils are preponderantly a permeable sandy loam. The underlying parent material, on the other hand, consists of a relatively impervious clay loam. Soil analyses by Whiteside (1951) show that the cultivated surface soil, to a depth of 4 in (10 cm), has a low phosphorus content, averaging 20 lb, as P_2O_5 , per acre (22 kg per ha). However, the phosphorus content increases with depth until relatively high values, up to 740 lb per acre (829 kg per ha) are encountered in the parent soils below 18 in (26 cm). Thus, the fertilizers leached from the surface into the sub-soils would tend to accumulate there and be rather slowly dissipated in the deeper ground-water drainage, e.g., springs. These statements concern cultivated rather than primitive soil conditions.

PHOSPHORUS CONTENT OF ELLERSLIE BROOK WATER

ANALYSES

Water samples from Ellerslie Brook were analyzed for their phosphorus content bi-monthly or monthly from September 7, 1949, to October 1, 1951. Soluble and total phosphorus were determined by Deniges' ceruleomolybdic method (Juday *et al.*, 1928; Robinson, 1941). Readings were made with a Lumetron photoelectric colorimeter. Ellerslie Brook in spate may carry considerable silt. This was largely removed from the samples before determinations by filtering through a No. 2 Whatman filter. Thus, phosphorus chemically or otherwise bound in the removed silt was unaccounted for. Results are expressed as milligrams of the element (P) per cubic metre, i.e., as parts per billion, (ppb).

TOTAL PHOSPHORUS

The total phosphorus content fluctuated markedly in the fall of 1949 and in 1950 (Fig. 1). In general, the rise and fall in phosphorus content in this period were directly associated with changes in water level of the brook (Fig. 2). Total phosphorus values ranged from 10–15 ppb with minimal flows to over 100 ppb with certain spates in the brook. The maximum determined value was 195 ppb on November 19, 1949.

In 1951, on the other hand, there were relatively minor fluctuations in the total phosphorus content, with poor or no direct association with changing water level (Fig. 1 and 2). Specific information on the amounts of fertilizers applied to the Ellerslie watershed in 1951 is lacking. However, data on phosphorus content of Ellerslie Brook, and general information that there was a small acreage of potatoes on fields adjoining the brook, are in agreement to indicate minor amounts of inorganic fertilizers applied to the watershed in that year.

As already indicated top soils in the watershed are highly porous. Phosphorus in fertilizers, if not utilized by crops and thus removed, or fixed in the soil complex in quite insoluble form (Dean, 1949), would be readily leached from top soils of cultivated land by precipitation. In both organic and inorganic forms, phosphorus would be removed from the top soils in the surface run-off or more permanently lodged in the relatively impervious sub-soils. From the latter, phosphorus from fertilizer would enter Ellerslie Brook more slowly, and at a more even rate, by way of springs and spring seepage, than in the surface run-off. Uncropped plant and animal growth would hold organically-bound phosphorus for varying and conceivably extended periods of time.

Most of the water discharged from Ellerslie Brook during spates is surface run-off from the watershed. Peaks in the total phosphorus content were encountered during spates and in the years when it is known that considerable quantities of fertilizers were applied to the land. It is concluded that the high phosphorus values resulted largely from surface drainage of cultivated fertilized fields. However, the leaching of the top soil was apparently quite rapid since a high phosphorus content in the surface run-off was not maintained, even with spates, much beyond

the year of fertilization. Whiteside (1950) found a low phosphorus content in the cultivated top soil of the Ellerslie watershed.

After the initial contribution from the leaching of top soils, manifest in the surface run-off, phosphorus from fertilizers applied to the land might still be expected to enter Ellerslie Brook in diminishing quantities for some time. In

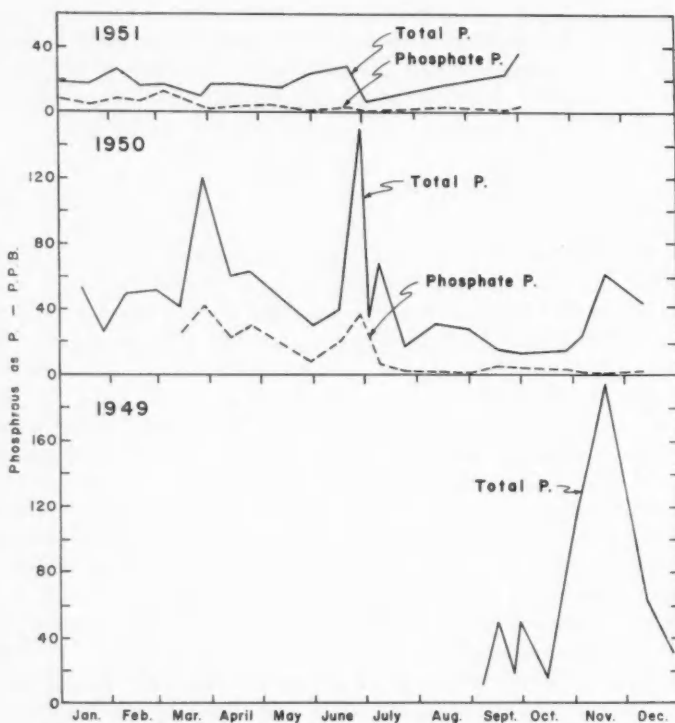


FIG. 1. Total and phosphate phosphorus content of Ellerslie Brook, P.E.I.

consequence the phosphorus content of the brook would continue above the primitive level. There is little information on the primitive phosphorus content of waters draining from uncultivated land on Prince Edward Island, or elsewhere in the Maritime provinces. Smith (1952) found that the average total phosphorus content of the surface waters of 8 Charlotte County lakes, New Brunswick, was 14 ppb during summer and early fall. These New Brunswick lakes receive drainage from a non-agricultural, forested area, with poor soils overlying granitic rocks. The total phosphorus content of Ellerslie water during 1951 averaged 18 ppb. This average value obtained when there was presumably little effect from recently

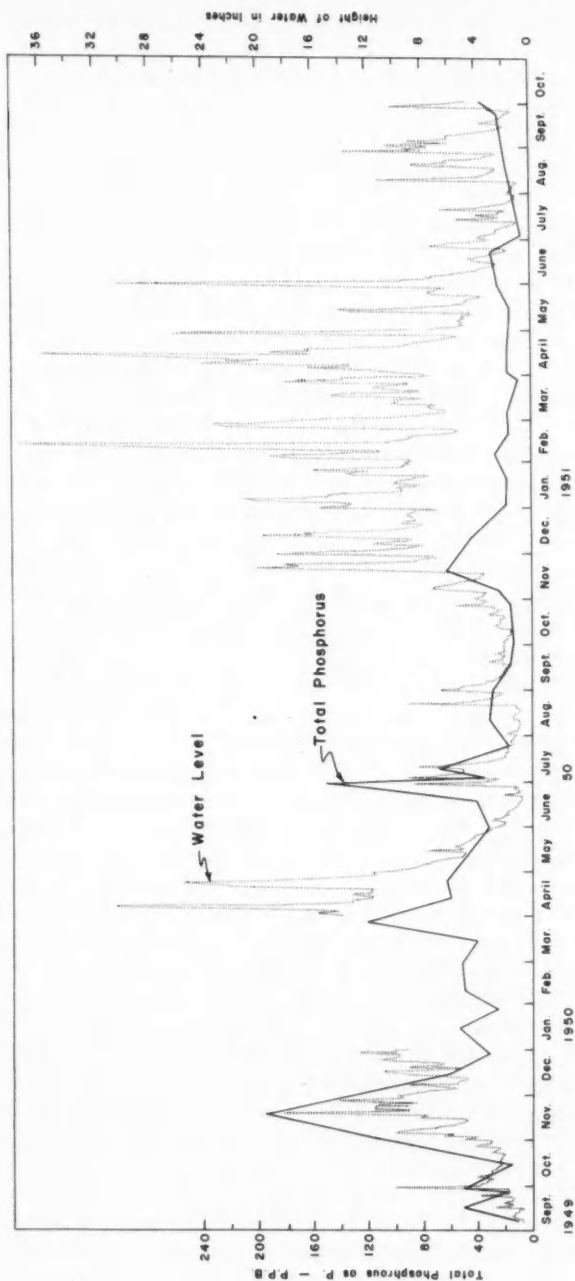


FIG. 2. Variations in total phosphorus content and water level in Ellerslie Brook, P.E.I.

fertilized fields. A comparison of the above data suggests that any continued enrichment of Ellerslie Brook from fertilizers was rather minor, at least at any one time, although substantial in aggregate over an extended period.

PHOSPHATE PHOSPHORUS

The phosphate (soluble inorganic) fraction of the total phosphorus content of Ellerslie Brook varied from 0 to 42 ppb as P (Fig. 1). The highest determined phosphate values were contemporary with high total phosphorus content of the water in the spring and early fall of 1950. In these periods, as well as during the same seasons in 1951, trends in phosphate and total phosphorus content were quite similar. This similarity of the two years was not manifest later in summer and into the fall. The phosphate phosphorus is directly available for bacterial and plant growth. Our general observations suggest that with the advance of summer the phosphate phosphorus was almost completely utilized by organic growth and bound into an organic form. Relatively high phosphate phosphorus values were encountered in late June, 1950, notwithstanding that this is a period of vigorous plant growth. Probably these high values resulted from run-off from recently fertilized fields before the phosphate could be fixed in another form.

AMOUNTS OF PHOSPHORUS DISCHARGED

Data on volume of water discharged, and determinations of phosphorus content, permit estimates of the amounts of phosphorus removed from the Ellerslie watershed by the brook drainage. An estimate for the period April 1 to December 15, 1950, amounted to 874 lb (396 kg) of phosphorus as P. In 1950, 2,112 lb (953 kg) of phosphorus were spread on the fields in the Ellerslie watershed. The fertilizers were applied in late May and in June. From June 1 to December 15, 1950, 414 lb (188 kg) of phosphorus were discharged by the brook. All of this amount did not originate from the fertilizers applied in 1950. The mean value for the 1951 determinations, 18 ppb, was taken as the level of total phosphorus in Ellerslie Brook when little affected by recent fertilization. Applying this level as a base line to the 1950 data, and considering the amount of phosphorus (223 lb, 101 kg) above this level as coming from the 1950 fertilization, we arrive at the estimate that about 10% of the farmers' fertilizers, at least as phosphorus, was lost through drainage in the year of application. Although crude, this estimate indicates that most of the phosphorus in fertilizers is not rapidly lost to the watershed. Much of the phosphorus is probably bound in the organic cycle on land and in the drainage waters. If this binding did not occur the watershed would obviously soon become impoverished. A hint of what may occur if run-off is unduly speeded by agricultural practices is given by the low-phosphorus values found by Whiteside (1950) in the permeable top soil of cultivated land in the Ellerslie watershed.

DISCUSSION

The assessed values for phosphorus in Ellerslie Brook waters represent the amounts of the element lost from the watershed. It is assumed, however, that

part of the phosphorus which finds its way into Ellerslie waters is incorporated into aquatic organic growth in the brook. Phosphorus from fertilizers, applied to cultivated fields in the watershed, make important contributions to the brook content. It is inferred, therefore, that the fertilization of fields materially enhances the productivity of Ellerslie Brook. Productive levels in the brook support this view. Production of brook trout is high (Smith and Saunders, 1955, 1958). When a pond was formed on the brook in 1952, strong eutrophic conditions were soon observed in the development of algal blooms and a rich bottom fauna.

Ellerslie Brook is quite typical of streams throughout Prince Edward Island. Ponds formed on Island streams have been found highly productive of plant and animal life (Loftus, 1948; Spence, 1952). Standing crops of trout to 100 lb per acre (112 kg per ha), or more, have been assessed, and yields to anglers are correspondingly good (FRB, 1958, p. 72; Smith, 1951, 1954).

Coupled with the fertility of the waters, other habitat qualities such as cool temperatures in summer, maintenance of good flow in streams throughout the year, and little competition from other fish species, make most Prince Edward Island streams and ponds excellent trout habitats. Cultivation and fertilization of land has apparently increased water fertility. Otherwise, comparable and suitable conditions for trout probably existed before the area was developed agriculturally. To what degree the greater fertility improved trout production over primitive levels is not known. However, the observations at Ellerslie Brook, and elsewhere on Prince Edward Island, support the conclusion that fertilization of farm lands has been and is an important factor in maintenance of the high level of trout production. It is inferred that this level is appreciably above that which obtained under primitive conditions.

Saltwater inlets, reaching well inland at the mouths of streams, are a prominent topographical feature of Prince Edward Island. These inlets, even well toward their heads, are sites for oyster farming, and in general they are productive areas. Phosphorus values obtained for Ellerslie Brook show that, at least during spates, considerable quantities of plant nutrients, which in good part originate from fertilizers recently applied to farm lands, are discharged into the inlets. Young *et al.* (1959) give a summer value for phosphate phosphorus in the surface water of Malpeque Bay, to which Ellerslie Brook is tributary by way of a typical oyster-growing inlet, as 9.2 ppb as P. During a spate on June 28, 1950, the phosphate phosphorus content of water being discharged from Ellerslie Brook into this inlet was 37 ppb as P (Fig. 1). These data suggest that at times freshwater discharge into a shallow and fairly confined inlet such as Ellerslie may provide sufficient increments of plant nutrients to result in phytoplankton pulses of importance to the survival and growth of larval oysters, and to the condition of adult individuals. It is of interest that Gaarder and Bjerkan (1934) advocated the use of waters receiving drainage from cultivated rather than uncultivated lands for oyster culture in Norway. On the other hand, Korringa (1956), working in South African estuaries, contends that estuarial fertility is derived in the main from the ocean itself, since the tributary fresh waters do not contain adequate nutrient supplies to account for the observed fertility.

SUMMARY

1. Commercial fertilizers applied to cultivated fields on the Ellerslie Brook watershed, Prince Edward Island, make substantial contributions of phosphorus to the drainage waters.

2. It is estimated that about 10% of the phosphorus put on the land is lost by discharge of water from Ellerslie Brook during the year of its application.

3. A major portion of the phosphorus is apparently bound into organic growth or otherwise fixed, and removed as crops or more slowly dissipated by drainage over longer periods of time.

4. Ellerslie Brook, in common with other Island streams, is highly productive of brook trout. It is inferred that fertilization of land is an important contributory factor to the production of trout in these streams, and in ponds formed on them. Oyster production in Prince Edward Island saltwater inlets receiving drainage from fertilized cultivated land may also be enhanced.

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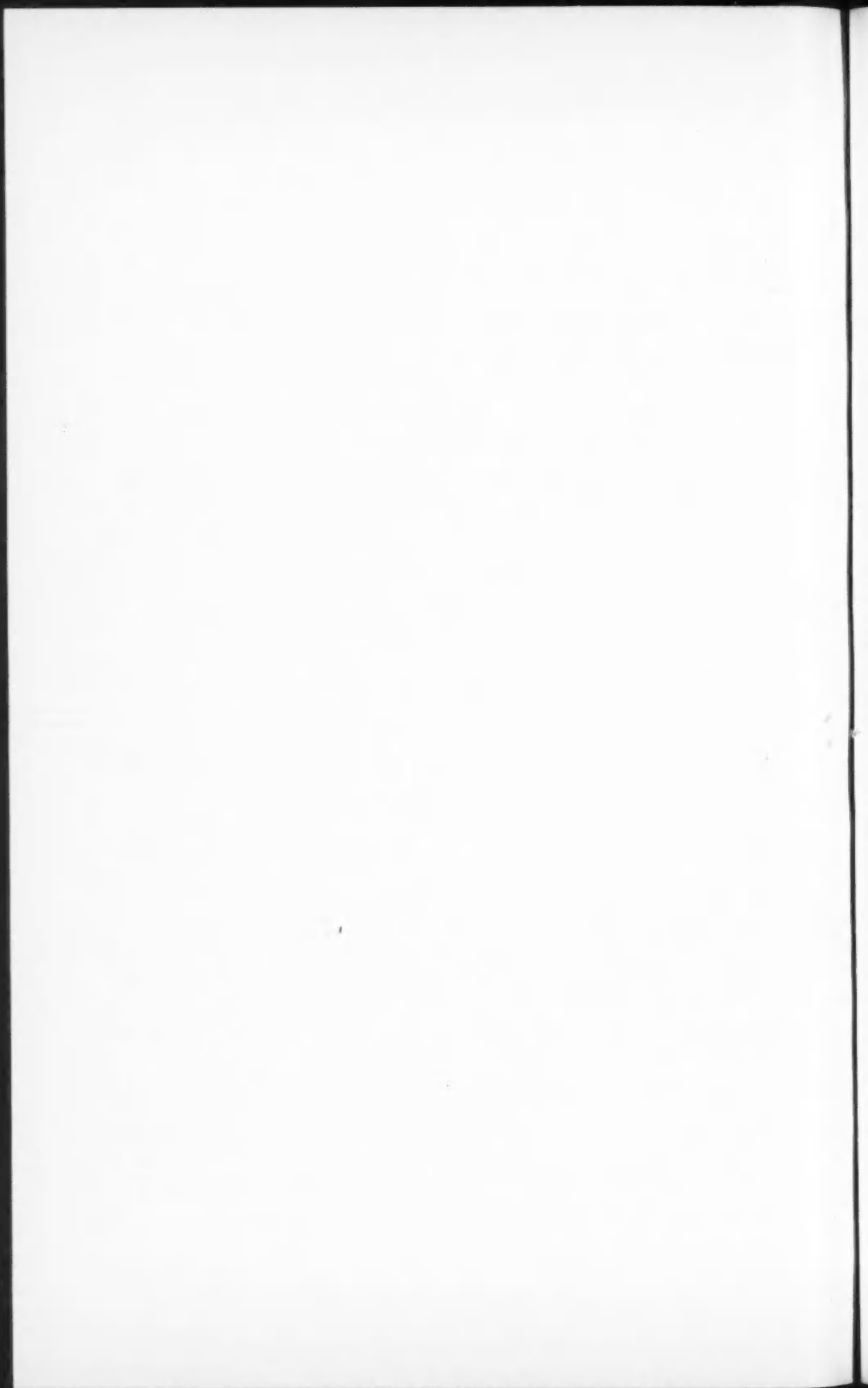
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Additional Observations Concerning Residual Sockeye and Kokanee (*Oncorhynchus nerka*)¹

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ABSTRACT

1. During the 1920's, plantings of anadromous sockeye fry in small barren lakes tributary to Stuart Lake produced (in addition to smolts) lake-maturing "residual" sockeye dull in colour at maturity. The samples taken contained a large excess of females. 2. The kokanee of Cultus Lake, caught in 1934-36, were all of one year-class and are now believed to have been progeny of Kootenay Lake (West End) kokanee eggs hatched and reared at Cultus Lake, though not *intentionally* planted there. These kokanee were of a bright colour at maturity, like their parent stock, and matured mostly at age 2+.

INTRODUCTION

ABOUT TWENTY YEARS AGO two papers appeared (Ricker, 1938, 1940) dealing with *residual sockeye* (lake-maturing progeny of anadromous sockeye) and *kokanee* (permanently freshwater stocks of sockeye). This note calls attention to a description of an additional stock of residual origin, and corrects my former assumption regarding the provenience of the Cultus Lake kokanee.

CRAWFORD LAKE RESIDUAL SOCKEYE

An experiment in rearing young sockeye during the 1920's inadvertently led to the production of residual fish. It is best documented by quoting the pertinent portions of the Annual Reports on Fish Culture of the Fisheries Branch of the Canada Department of Marine and Fisheries (later the Department of Fisheries) for 1928-30, written by H. C. Crawford, Superintendent of the Stuart Lake Hatchery.

Report for 1928, page 31:

"The distribution of sockeye fry from the Stuart Lake hatchery in barren lakes in the vicinity has for several years given splendid returns in the way of migrating fingerlings and yearling fish. The usual migration did not occur last season [spring of 1928], and on investigation it was found that in both Crawford and Rainbow lakes the sockeye had apparently become landlocked, as twenty sockeye were caught in one night's fishing ranging in size from what appeared to be two-year-old fish to several carrying eggs in a well developed state."

Report for 1929, pages 31-32:

"Crawford and Rainbow lakes which have been used as natural retaining ponds or nurseries for fry were not planted in the spring of 1929 because numbers of sockeye planted

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there in previous years did not migrate as yearlings but became land-locked. These land-locked fish have proven exceptions to the generally accepted belief that sockeye must go to sea before they reproduce, and also that sockeye die after their first spawning. During 1929, 69,000 sockeye eggs were collected from Crawford and Rainbow lake fish. These fish had never left the lake, since the outlet stream is so precipitous that it is impossible for salmon to ascend it from the lower level.

"Crawford lake, which is about 730 yards long, 280 yards wide and 33 feet deep, had been found teeming with natural fish food but barren of fish. It was planted with sockeye fry for the first time in 1921. Most of the fish from this distribution left the lake of their own accord about the middle of May and the middle of June, 1922, when they ranged from $3\frac{1}{2}$ to $5\frac{1}{2}$ inches in length. Fry planted in 1922 averaged about 2 inches in length in June of that year and in the following year they migrated in very large numbers. In 1924 equally favourable results were observed, though the average size of the fish was, if anything, larger than in previous years. In 1925, when migration started on May 17, the fish were apparently of rather smaller size than in former years, but at the same time a small percentage of larger-than-average size fish were observed and were considered to be two-year-olds. Two distinct sizes were noticed—one averaging $4\frac{1}{2}$ inches and the other 7 inches. This was the first time that fish of this larger size had been seen among the migrants from Crawford lake. A small percentage of fingerlings or fish in their first year was noticed each season in the general migration, but in 1926, such fish were present in greater numbers than usual. In the following year an increase was observed in the number of large fish, two-year-olds, and a decrease in the general run. Practically no migration of yearling sockeye was observed in 1928, and it was decided to discontinue further stocking for a period of three years.

"In the autumn of 1928 a test net was set and 20 sockeye ranging from two-year-olds to mature land-locked fish carrying eggs were caught in one night. The collection of land-locked sockeye eggs was undertaken in the autumn of 1929. Four hundred and ninety-six fish were caught. The females, most of them ripe when taken, greatly out-numbered the males. Out of 307 fish up to September 4, only 36 were males. The spawners were a dirty greyish green on the back and sides and a mottled grey underneath. The fish containing immature eggs were a bright silvery colour. Unlike sockeye that return from the sea, these land-locked fish did not turn red. The eggs collected were of poor quality, a condition partly attributed to the scarcity of males and the manner in which the fish had to be taken, namely, in gillnets.

"In order to further test the theory that all sockeye die after their first spawning, 7 spawned fish were placed in pens and kept under observation for a period of two weeks. At the end of that period they were in a better and more vigorous condition than they were when first placed in the retainers.

"Efforts are being made to decrease the numbers of land-locked sockeye in Crawford and Rainbow lakes with a view to restoring these lakes to their former condition as excellent natural retaining ponds, and with this end in view, 496 such fish were netted and removed from the former and 1,078 from the latter.

"Fourteen thousand one hundred and fifty land-locked sockeye eggs and fry from the 1929 collection were planted in Cunningham Creek." [The table on page 77 shows that 10,250 of these were planted as eyed eggs, and 3,900 as fry.]

Report for 1930, page 30:

"Two hundred and three sockeye that had become land-locked in Crawford and Rainbow lakes were destroyed with a view to returning these lakes to their original state, when they made excellent natural rearing ponds for sockeye fry."

Crawford Lake and the other lakes mentioned are situated south of Stuart Lake, in central British Columbia (Lat. $54^{\circ} 35'$, Long. $125^{\circ} 10'$), in the vicinity of the portage to Babine Lake. Their lake-maturing sockeye could have been from

several parent stocks. During the 1920's eggs for the Stuart Lake hatchery were obtained from outside sources, as follows:

Spawning years 1920, 1921, 1927: from Pierre and 15-mile Creeks, Babine Lake (tributary to upper Skeena River)

Spawning years 1922, 1923, 1924, 1928: from the Birkenhead River (Harrison Lake system, tributary to the lower Fraser River)

Spawning years 1925, 1926: from Lakelse Lake (tributary to the lower Skeena River)

Apparently fry were planted in Crawford Lake annually from 1921 to 1928 (spawnings of 1920-1927), so that the original freshwater-maturing fish may have been from any or all of the three brood stocks above. There is no mention of any return of anadromous sockeye to the outlet streams of these lakes, or to other nearby streams.

The body colour of sockeye in all three of the donor areas is the usual bright red at maturity. The mature Crawford Lake fish were dull green colour—the same change from parental colour as was observed among Cultus Lake residual sockeye.

It is impossible to know whether the Crawford Lake mature fish taken in 1928-30 were the direct survivors of the fry planted (true residuals), or were the progeny of such survivors, or were a mixture of both. The excess of females taken is the reverse of what was found among Cultus Lake residuals, where there was a very heavy excess of males.

Another instance of colour difference between lake-maturing and anadromous *nerka* of the same stock is given by Rounsefell (1958), quoting M. G. Hanavan and L. A. Fulton. In this case the parent stock were kokanees of Lake Wenatchee, Washington, a tributary of the Columbia River. These are 7-8 inches long and "a dull olive green at maturity . . . though rarely a red individual was observed on the spawning grounds." Progeny of these small fish, marked and released, went to sea (at least in part); they returned in very good numbers, as fish of the normal sockeye ages, and were a bright red colour at maturity; the age 3+ fish (the great majority) were only slightly smaller than the unmarked sockeye of the same year.

The 1929 eggs taken from the Crawford Lake freshwater sockeye apparently developed normally and produced normal fry. The Stuart Lake hatchery was closed in 1931, and no later information is available concerning the sockeye in Crawford Lake and adjacent lakes. It would be most interesting to go back and find whether their descendants are still in these lakes, and the present appearance, size, etc., of any surviving stocks.

One unusual feature of the account of the Crawford Lake fish is the apparent "mending" of the freshwater sockeye spawners after their eggs were taken—though the period of retention was only 2 weeks. However, L. R. Donaldson (quoted by Robertson, 1957) examined 3 male and 2 female "kokanee" 9 to 10 inches long taken in spring in Chapman Lake, Washington, which were feeding and in good condition, yet showed "undoubted evidence" of previous spawning.

KOOTENAY LAKE SOCKEYE IN CULTUS LAKE—A CORRECTION

Recently Vernon (1957) published a detailed morphological study of the kokanee in Kootenay Lake, demonstrating that the three arms of the lake (North End, South End and West End) contain three distinct stocks of kokanee, whose differences are partly inherited. (The lake has no anadromous sockeye.) Apart from its great intrinsic interest, the information in Vernon's paper has reopened the question of the origin of the Cultus Lake kokanees—which in my earlier papers were regarded as of native Cultus Lake stock.

Of the years when gill-netting was done in Cultus Lake, kokanees were taken only in 1935 and 1936; a single specimen was taken by dip net in 1934—one of two which appeared at the outlet of the Smith Falls hatchery ponds. All specimens were taken in late August or early September, and were mature or (usually) partly spent. Many gill-net sets were made at this season also in 1937, and a few in 1932 and 1934, but these yielded no kokanee. Their absence in 1937 caused no great surprise at the time, partly because the numbers of sockeye at the lake are very variable, so it seemed natural that kokanee should be too; partly also because the number of kokanee caught was never very great: 13 were taken in 1935, only 2 in 1936.

The maturing kokanee obtained exhibited increasing average size over three successive years: 223 mm fork length in 1934 (1 specimen), 346 mm in 1935 (13 specimens) and 402 mm in 1936 (2 specimens); see table VIII of Ricker (1938) for details. The kokanee of these three years had *minimum* ages (read from the scales) of 1+, 2+ and 3+, respectively. This strongly suggests that they all belonged to a single year-class, which would be the 1932 year-class (spawned in 1932 and hatched in 1933) if the minimum age interpretation were correct.

Now kokanee of the 1932 year-class were hatched and reared during 1933 at the Smith Falls Hatchery tributary to Cultus Lake, and while none were intentionally released into the lake, the vagaries of hatchery operations make it likely enough that a few would escape. Arguing against this possibility is the fact that the scale margins of all these (mature) specimens were resorbed, and the diameter of what remained, relative to the size of the fish, suggested that an additional year's growth had completely disappeared in each case (see Ricker, 1938). However, no scale measurements were published; the mounted scales are no longer available; and kokanee specimens sent to a museum dried out when their jar cracked, and were discarded. I no longer have any detailed recollection of the circumstances, but I might have been influenced by a feeling—quite unjustified, as it turns out—that kokanee, like Fraser River sockeye, ought to mature mostly at age 3+ ("four-year-olds").

The kokanee brought to Cultus in 1932 were from the Nelson hatchery near the outlet of Kootenay Lake, and comprised about 200,000 eggs from a collection of 1,250,000 taken in the fall of 1932 from three West End streams: 950,00 from Kokanee Creek, 195,000 from Six Mile Creek, and 105,000 from Redfish Creek (Crawford, 1933). West End kokanee of Kootenay Lake mature mostly at age 2+, but with a few at 1+; they have bright colour and marked scale resorption at maturity (Vernon, 1957). This colour and degree of scale resorption agree

with the kokanee netted in Cultus Lake, and the ages correspond to the *minimum* estimate above. The average length of the maturing kokanee in Cultus was about 100 mm greater than that of the West End Kootenay stock; average fork lengths are given by Vernon as 247 mm and 238 mm for Kokanee Creek and Redfish Creek in 1951 (sexes combined). Warmer temperature or longer growing season at Cultus may have permitted this more rapid growth.

In time of spawning, the Cultus kokanee were somewhat earlier than those of Kootenay Lake, and much earlier than the native Cultus sockeye and residuals. Vernon (p. 587) gives September and October as the spawning season for Kootenay kokanee, with the West End stock starting their spawning about a week later than that of the South End and a week earlier than that of the North End. The height of the West End spawning season would therefore be about the end of September, whereas it averaged the first week of September in Cultus Lake. The native Cultus sockeye spawned from late October to late December, with a peak about the middle of November; the residuals (in 1936) were apparently a week or two earlier, to judge from gill-net catches (Ricker, 1938, fig. 6).

If the kokanee found in Cultus Lake were of Kootenay Lake origin, as now seems practically certain, my earlier speculation about their evolution from the local sockeye via residuals is obviously inapplicable (Ricker, 1940). This of course does not destroy the interest of the comparison that can be made between the residual sockeye and *a* kokanee stock, both reared in the same environment, nor does it necessarily invalidate the hypothesis that kokanee have originated from residual stocks in many lakes. The story of Crawford Lake, given above, suggests that the initial stages of kokanee evolution may be quite easy when there exists stringent selection against the anadromous type (in that case, complete selection). Also, it is tempting to imagine that the dull Lake Wenatchee kokanee, which so easily reverted to anadromous life, had evolved from residuals in that lake during the present century because of selective elimination of sea-run individuals by the increasing hazards affecting those which migrated (loss of smolts in irrigation water diversions, a dam with an inadequate fishway, and the fishery).

On the other hand, grey-green colour is not a universal mark of residual sockeye: many of those of Baker Lake were at least fairly bright red (Ricker, 1938). Nor are dull hues restricted to residuals: the South End Kootenay Lake kokanee were dull (Vernon, 1957), and even the anadromous sockeye of Alistair Lake, a tributary of the lower Skeena, mature mostly in dull greens and yellows, rarely any conspicuous red (J. MacDonald and W. E. Johnson, personal communication).

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Some Morphological Differences Between the Subspecies
of Cutthroat Trout, *Salmo clarkii clarkii* and *Salmo*
clarkii lewisi, in British Columbia¹

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ABSTRACT

Coastal cutthroat trout, *S. c. clarkii* Richardson, occupy most lakes and streams of coastal British Columbia, including the adjacent islands. Yellowstone cutthroat, *S. c. lewisi* (Girard), occupy southeastern British Columbia; their range is separated from that of the coastal subspecies by a zone lacking cutthroat trout. A map showing all natural distribution records in the province is presented. From 60 to 146 specimens were examined for distinguishing characters. Spots below the lateral line are more numerous towards the anterior end in *S. c. clarkii*, but more numerous towards the posterior end in *S. c. lewisi*. A plot of spot number in selected areas of the body provides almost complete separation of individuals of the two subspecies. Significant differences also occur in certain scale counts and in body and peduncle depth, although these characters overlap considerably between the subspecies. No difference was found in vertebral count.

INTRODUCTION

THE TROUT of western North America have received considerable attention from systematists, and many species and subspecies have been recognized. Assessment of the myriad named forms has become increasingly difficult as natural populations have been widely disturbed or eradicated by watershed impoundment, by the increasing use of fish poison, and by indiscriminate stocking of non-native forms.

This study was carried out in order to record the natural distribution, and some of the morphological characters, of native populations of cutthroat trout in British Columbia, before they became seriously disturbed. Emphasis has been on the external characters separating the two subspecies of cutthroat as presently recognized in British Columbia. The study is based on examination of records and specimens from the literature, from the Provincial Museum in Victoria, and from the Institute of Fisheries at the University of British Columbia.

GEOGRAPHICAL DISTRIBUTION

Cutthroat trout in British Columbia occupy two distinct areas, separated by a zone lacking any native populations (Fig. 1). The subspecies (as defined by Bailey, Winn and Smith, 1954) occurring in the southeastern portion of the province had its origin in the region of the upper Columbia and Missouri Rivers, south of the margin of pleistocene glaciation. The coastal subspecies probably achieved its present distribution in the province through the sea.

The fish occupying the two areas in British Columbia are quite distinctive in appearance although south of British Columbia the morphological features of the two subspecies tend to merge and their distributional areas tend to overlap.

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COASTAL CUTTHROAT TROUT—*Salmo clarkii clarkii* Richardson (Fig. 2). This subspecies is found in practically all lakes and streams of the coastal region (Dymond 1932, 1936; Carl and Clemens, 1953; Lindsey, 1957). It occurs throughout the lower Fraser Valley, but there is only one authenticated record

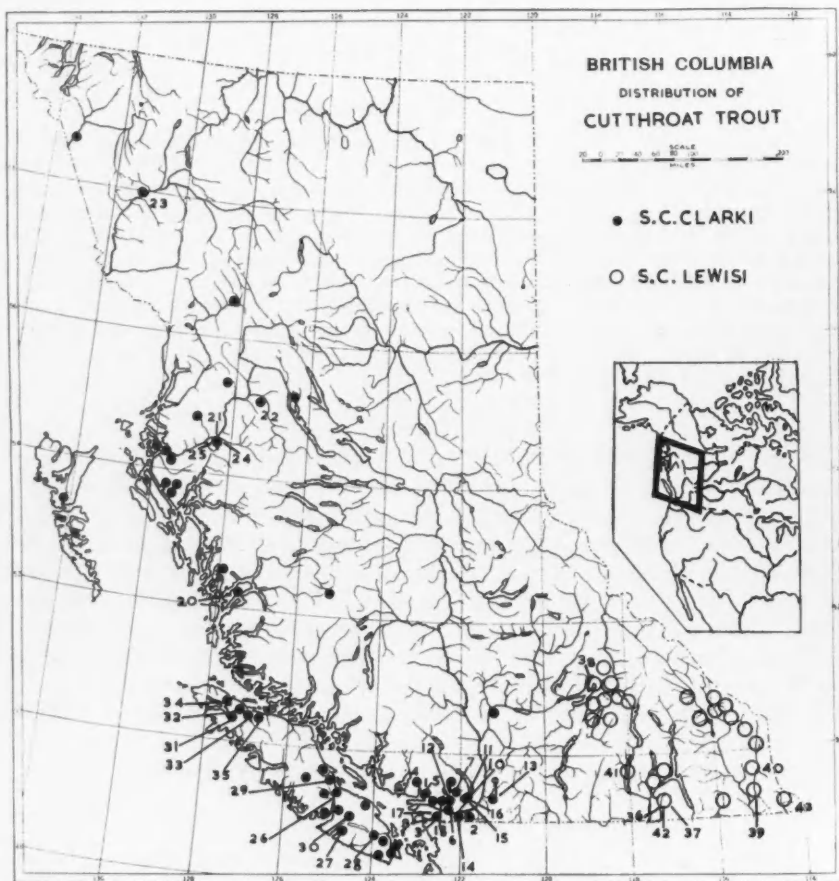


FIG. 1. Natural distribution of coastal and yellowstone cutthroat trout. Specimens from numbered locations are those used for this study.

from above the Fraser Canyon, namely a specimen caught in the Thompson River near Ashcroft in 1926 (Royal Ontario Museum specimen No. 4005). Cutthroat have been questionably reported to occur in Big Bar Lake north of Clinton, B. C., but recent collections there have yielded only rainbow trout (*Salmo gairdnerii*). Cutthroat have been taken in the Skeena system as far inland as Morrison Lake, in the Nass as far inland as Damdochax Lake, and from the lower

Taku River. Their probable northern limit is Prince William Sound in southeastern Alaska. Cutthroat are widespread on Vancouver Island, on the Queen Charlotte Islands and other coastal islands.

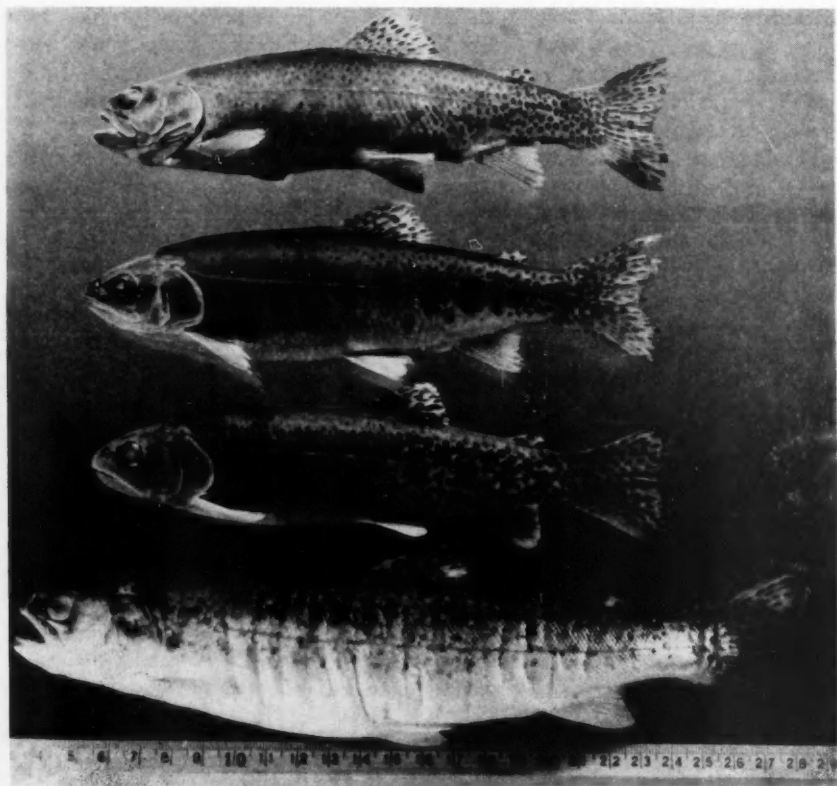


Fig. 2. Yellowstone and coastal cutthroat trout showing a high and low number of spots in each subspecies (scale in centimetres). From top to bottom:

S. c. lewisi, with a high number of spots, from sample BC56-49

" , with a low number of spots, from sample BC57-327

S. c. clarkii, with a high number of spots, from sample BC56-52

" , with a low number of spots, from sample BC56-87.

YELLOWSTONE CUTTHROAT TROUT—*Salmo clarkii lewisi* (Girard) (Fig. 2). This subspecies is found in the southeastern portion of the province, from Flathead River north along the Alberta border at least as far as Magog Lake, and west to the Arrow lakes. Included also are populations from the extreme eastern headwaters of the Thompson River in the Revelstoke area, and from tributaries to Kootenay Lake; these have been described as a separate subspecies (*Salmo clarkii*

alpestris) by Dymond (1931). A sample of fish examined from the Revelstoke area lacks clearcut distinguishing characters; this and the lack of a discrete geographic range creates suspicion about the validity of *S. c. alpestris*.

Annual Reports of the British Columbia Game Commission record large-scale plantings, in coastal and island water, of yellowstone cutthroat eggs collected in the Cranbrook area, in the early 1930's. No evidence of survival of the interior subspecies in coastal waters has been found in the present study. More recently, coastal cutthroat trout have been planted in Garcia Lake near Merritt, in the Similkameen system, and upper Shuswap River near Cherryville, and it remains to be seen if these become established.

A taxonomic complication arises from the frequent hybridization between *S. clarkii* and the rainbow trout, *S. gairdnerii*. Such hybridization is less common in areas where the two species occurred naturally, than in areas originally containing only one species and into which the other species has been introduced. For some years hybrids were produced artificially for fish cultural purposes, and planted in the Kootenay area under the name "Cranbrook trout". In the present study any suspected hybrid individuals have been discarded.

MATERIALS

The fish used for this study are deposited in the Museum of the Institute of Fisheries of the University of British Columbia. These specimens were donated by various organizations, such as the British Columbia Game Commission, the Fisheries Research Board of Canada, and by many individuals. Detailed data for the individual fish can be borrowed from the Institute for study.

Only fish collected in British Columbia waters were studied. The coastal cutthroat were from 3 major regions—Lower Mainland; northern British Columbia, including Lakelse Lake; and Vancouver Island. The yellowstone cutthroat trout were from 6 localities in southeastern British Columbia (Appendix Table A).

The number of fish used for counts of scales, vertebrae and spots are shown in Table I.

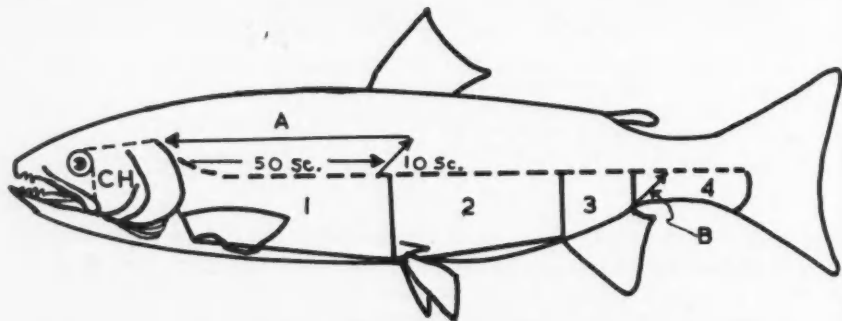


FIG. 3. Areas 1, 2, 3 and 4 below the lateral line and the cheek (CH) on which spots were counted. Scale rows were counted on the side of the body at level "A" and also at "B" — from the insertion of the anal fin to the lateral line.

TABLE I. Number of fish used for different counts and measurements, and their size (fork length).

Character	<i>S. c. clarkii</i>		<i>S. c. lewisi</i>	
	No. of fish	Length range	No. of fish	Length range
		cm		cm
Scales	83	7.6-40.5	60	9.3-20.7
Vertebrae	75	9.2-40.5	65	9.6-21.9
Spots and general colour pattern	141	4.8-40.3	146	3.3-27.1
Spots on cheek	60	9.2-40.5	98	7.4-21.9
Relative growth	67	9.2-40.5	64	9.3-21.9

SCALES

ANTERIOR BODY SCALE COUNT

The first scale count used in this study is one suggested by Neave (1943). To locate the point where the count begins, 50 scales were counted backward along the lateral line, then 10 scales obliquely upward and backward (including the lateral line scale as one); starting with and including this scale, the number of oblique scale rows was counted at this level forward, as far as the edge of the opercle ("A" in Fig. 3). This count gives a measure of the branching of the scale rows proceeding dorsally from the lateral line, and may also reflect a variation in the pattern of scale rows above the opercle.

Figure 4 and Appendix Table B show these counts. In coastal cutthroat, the mean was 81.7, significantly less than the 91.1 for yellowstone cutthroat.

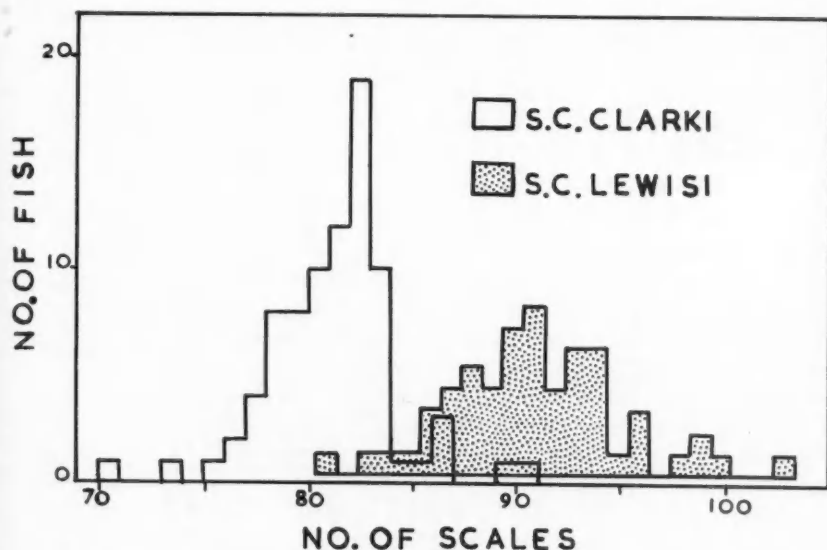


FIG. 4. Number of scale rows on the anterior region of the body for the two subspecies.

ANAL INSERTION TO LATERAL LINE SCALE COUNT

The second scale count made was from the insertion of the anal fin upward and obliquely backward to the lateral line ("B" in Fig. 3). Results are given in Fig. 5 and Appendix Table C. Coastal cutthroat counts averaged 18.2, substantially less than the 21.8 for yellowstone cutthroat.

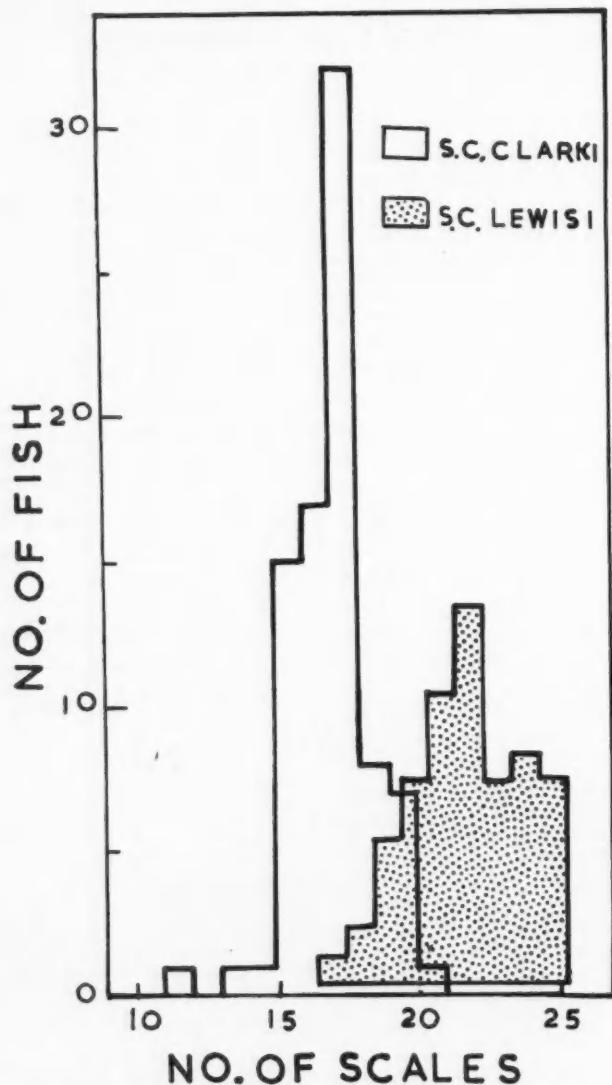


FIG. 5. Number of scales from the insertion of the anal fin to the lateral line for the two subspecies.

CRAZY CREEK POPULATION

The same two scale counts were made on populations of *S. c. lewisi* from Crazy Creek, a tributary of Eagle River (Fig. 1, 38); they are compared with samples from the Kootenay River (Fig. 1, 39), and the Flathead River (Fig. 1, 43) in Table II. Both these counts indicate a somewhat higher number of scales

TABLE II. Number of scales in *S. c. lewisi* from southeastern British Columbia, on two regions of the body.

Sample No. (see Fig. 1)	38	39 and 43
Museum No.	BC55-347	BC55-351 and BC57-327
Site	Crazy Ck.	Kootenay R. and Flathead R.
No. of fish	25	35

SCALES IN THE ANTERIOR BODY REGION (as defined on page 000; A, Fig. 3)		
Range	81-103	81-100
Mean	92.8	89.8
Median	92	90
Standard deviation	2.85	4.21

SCALES FROM INSERTION OF ANAL FIN TO LATERAL LINE (B, Fig. 3).		
Range	21-25	17-25
Mean	22.5	21.4
Median	22	21
Standard deviation	1.24	2.29

in the Crazy Creek population, which was described as *S. c. alpestris* by Dymond (1931). However the overlap in the number of scales and in geographic distribution makes it difficult to separate the two populations at the subspecific level².

OTHER SCALE COUNTS

Other scale counts contrasting the two subspecies have been recorded in the literature, and are presented in Table III. While there are inconsistencies (in part due to use of specimens from widely differing localities) there is an evident tendency for the interior form to have higher scale counts than the coastal form.

In summary, the counts previously recorded and those reported here indicate that *S. c. lewisi* has on the average smaller and more numerous scales (probably resulting from more frequently branching rows) than has *S. c. clarkii*. There is however overlap in all these characters so great as to prevent the separation of many of the individual fish into two distinct groups.

²In a related species, Rawson (1953) has suggested a shift in scale count in second and third generations of *S. gairdnerii kamloops* toward the high elevation form *S. g. whitehousei*, when planted in an alpine type lake. Probably, a similar shift toward a high number of scale count in *S. c. alpestris* from *S. c. lewisi* may have been brought about with the difference in environment.

TABLE III. Comparisons of the number of scales in three subspecies, after various authors.

Authors	Scales in lateral line	Scales in 1st row above lateral line	Scales above lateral line	Scales below lateral line
<i>S. c. clarkii</i>				
Carl and Clemens (1953)	...	143-180 (usually 150-158)	...	...
Jordan and Everman (1896)	150-164 cross series	...	...	...
Miller (1950)	143-230 (usually 150-180)	...	...	...
Neave (1943)	116-133 (av., 122.8)	...	...	...
a) Cowichan Hatchery				
b) Veitch Creek	116-126 (av., 119.5)	...	35 or fewer	35 or fewer
Schultz (1936)	120-180 (usually fewer than 160)	...	...	...
Snyder (1908) (1940)	140-170 160-200	... ...	... 34	... 40
<i>S. c. lewisi</i>				
Carl and Clemens (1953)	...	150-175 (usually 165)	...	...
Jordan and Everman (1896)	145-170	...	32	42
Schultz (1936)	156-190 (usually 165-170)	...	35	38
<i>S. c. alpestris</i> ^a				
Carl and Clemens (1953)	...	200-230 (usually 218)	...	...
Dymond (1931)	...	200-230 (usually 218)	...	...

^aHere regarded as *S. c. lewisi*.

VERTEBRAE

Vertebral counts of specimens of both subspecies, made from X-ray plates, are presented below; the hypural bone is included as a vertebra. Counts on coastal fish from three major areas (Lower Mainland, Lakelse Lake and Vancouver Island) are lumped together, as they displayed no apparent differences (Appendix Table D).

Number of vertebrae

	60	61	62	63	64	Mean	Median	Standard Deviation
<i>S. c. clarkii</i>	7	42	20	5	1	61.35	61	1.21
<i>S. c. lewisi</i>	12	34	15	3	1	61.18	61	0.28

No significant difference exists between these vertebral counts, despite the fact that the individuals must have developed under somewhat different environmental conditions. The means are in keeping with a mean vertebral count of 61.00 reported by Hartman (1956) for hatchery-reared coastal cutthroat.

BODY PROPORTIONS

Measurements of the depth of the body at the origin of the dorsal fin, and the least peduncle depth, are presented in Fig. 6. The tendency towards deeper body and peduncle in *S. c. lewisi*, which is apparent from these measurements,

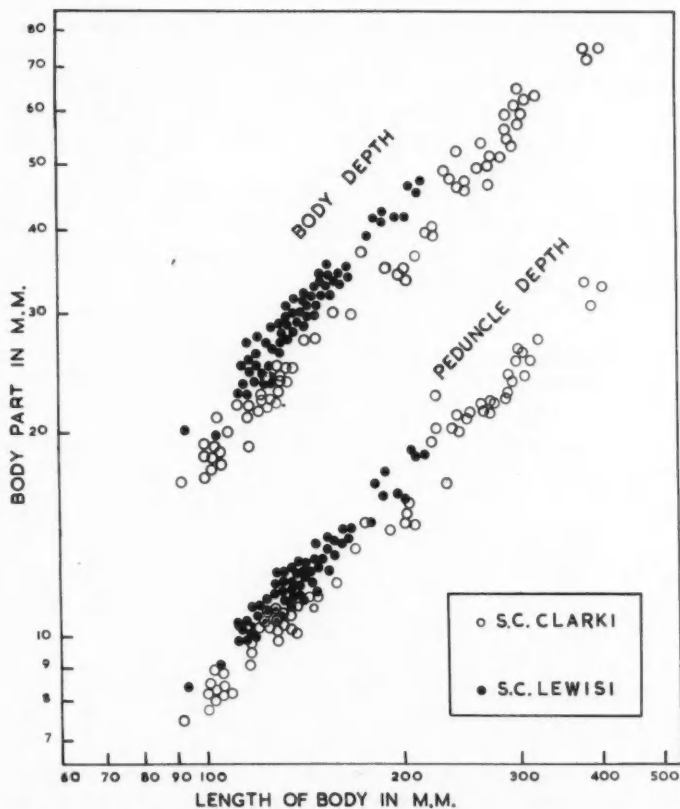


FIG. 6. Depth of the body at the origin of dorsal fin and the least peduncle depth against the standard length of the body, for the two subspecies.

is also visible in the specimens shown in Fig. 2. However, as in scale counts, overlap between the subspecies is too great to allow separation of all individuals on these characters alone.

SPOTTING

Only Snyder (1940) made actual counts of the spots on *S. c. clarkii*, and showed that the number of spots on the head were 26 to 71 and on the body 322 to 577. Other workers, Miller (1950), Carl and Clemens (1953), DeWitt (1954), and Weisel (1957), have described the colour pattern in general.

In this study, all the spots on the fish below the lateral line were counted. To accomplish this, the area of the fish below the lateral line was divided into four rectangular areas, shown in Fig. 3. Only Area 1 needs some explanation. This rectangle covers the area between the opercular opening and a perpendicular drawn from the origin of the pelvic fin to the lateral line. The base of the rectangle is a line which joins the lower base of the pectoral and the origin of the pelvic fin.

Spots were counted by passing the fish under different sized windows cut in white paper. The fish was passed under the window forward, i.e. head first. Spots were counted in the small area, visible through the window; then the paper was moved forward to leave the area (in which spots had been counted) behind. Again spots in the immediate adjacent area were counted. This process continued till the whole fish up to its caudal fin was covered.

Size of the spot was not considered. Only spots visible to the naked eye were counted. Specking, parr-marks or big parr-mark-like spots were not considered. Fused spots were counted as one. The spots which fell on the perpendiculars separating the areas were not counted.

TABLE IV. Number of spots in the different areas of the body, as outlined in Fig. 3.

		<i>Salmo clarkii clarkii</i>			<i>S. c. lewisi</i>
	Vancouver Is.	Lakelse and northern B.C.	Lower mainland	Total	Southeastern B.C.
No. of fish	58	36	47	141	146
SPOTS, AREA 1					
Range	16-250	3-176	2-120	2-250	0-43
Mean	111.39	68.11	51.65	80.43	8.00
Median	108	56.5	46	57	6
St. devn.	70.63	33.89	26.71	57.37	7.52
SPOTS, AREA 2					
Range	6-150	8-100	2-80	2-150	1-52
Mean	67.67	43.13	27.95	48.17	9.42
Median	61.5	37	24	37	8
St. devn.	43.20	22.16	16.23	35.77	6.99
SPOTS, AREA 3					
Range	5-56	4-53	0-25	0-56	1-25
Mean	23.44	17.69	10.40	17.63	9.61
Median	21	15	9	13	10
St. devn.	13.92	10.87	5.83	12.28	5.15
SPOTS, AREA 4					
Range	3-67	4-44	0-29	0-67	0-44
Mean	20.72	14.75	12.42	16.43	17.63
Median	16	13.5	13	13	18
St. devn.	13.45	8.79	6.27	10.99	9.09

Table IV and Appendix Table E give the results of spot counts in the 4 areas below the lateral line. The number decreases from the head towards the tail in all samples of coastal cutthroat, while the reverse is true for yellowstone cutthroat. There is some overlap between the subspecies in each body area, but almost complete separation is achieved by plotting number of spots in Area I against those in area 4 (Fig. 7). A similar plot of spots in Area I against those in Area 2, not shown here, gives almost as good separation.

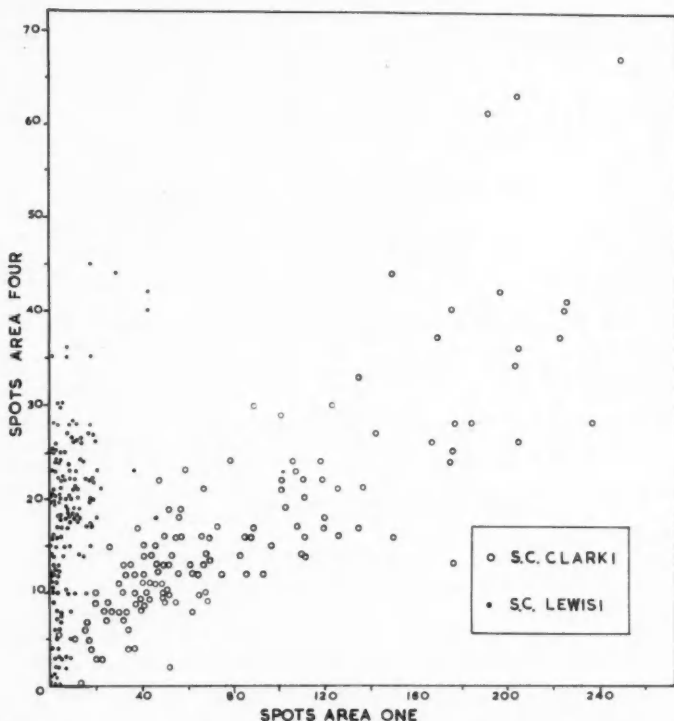


FIG. 7. Number of spots in body Area 1 plotted against the number of spots in Area 4, for the two subspecies.

Spots were also counted on the cheek and opercle, in an area bounded on top by a line from the upper margin of the eye to the top of the opercular slit, and on the front by a line from the posterior margin of the eye to the posterior tip of the maxilla (Fig. 3). Counts for the two subspecies are presented in Fig. 8 and Appendix Table F. Spotting on the cheek is evidently more intense in coastal than in yellowstone cutthroat, although some overlap in spot number occurs.

In addition to the spot counts recorded above, other differences were observed. In some individuals of *S. c. clarkii* the pectoral and pelvic bases, the entire

anal fin and the belly were spotted. These areas were usually immaculate in *S. c. lewisi*, although a few fish had spots on the belly and base of the anal fin.

No consistent differences were observed between the subspecies in spotting or colour pattern on the dorsal and adipose fins, snout, inter-orbital space, or sides above the lateral line.

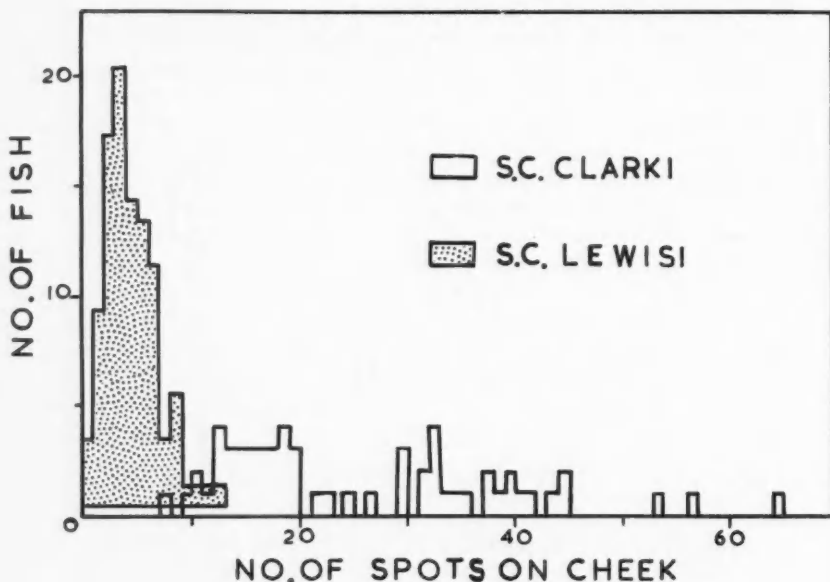


FIG. 8. Number of spots on the cheek for the two subspecies.

The pattern of spotting is evidently the best criterion, of those examined, for separating the two subspecies. The degree of overlap in spot counts is comparatively small and is least when counts in body Area 1 and Area 4 are compared.

CONCLUSIONS

The subspecies *S. c. clarkii* and *S. c. lewisi* occupy geographically distinct areas, separated in British Columbia by a zone lacking native cutthroat populations. Their natural ranges have probably merged in the State of Washington where the picture of their original distribution and morphology has been much obscured by man's activities. In addition to geographic discreteness, the subspecies are characterized by morphological differences which, in the case of spotting, show almost no overlap between specimens from the two areas. Spotting below the lateral line has been found to be the best character to separate the subspecies, but certain scale counts and body proportions show significant differences. Within the region

studied, differences in geographical distribution, morphological characters and coloration justify recognition of two subspecies of cutthroat trout.

ACKNOWLEDGMENT

My thanks are extended to Dr. C. C. Lindsey for suggesting the problem and guiding throughout the course of this study. The writer also appreciates the valuable suggestions and criticisms of the manuscript received from Dr. W. A. Clemens and Dr. P. A. Larkin. Miss Betty Barrett of the University Health Service X-rayed the fish.

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APPENDIX TABLE A. Fish collections used for this study, and their approximate location. Collections marked with an asterisk were used for vertebrae, scales, spots on cheek, and depth of body measurements. All collections except No. 2 and No. 18 were used for counting the spots below the lateral line. Collections No. 2, 3, 4, 6, 9, 13 and 18 were also used for scale counts. "Museum No." in this and subsequent tables refers to the Museum of the Institute of Fisheries of the University of British Columbia. (The position of each collection, shown in the last three columns, is given in the form used by the 1953 British Columbia Gazetteer. Geographical quadrilaterals of 1 degree to a side are identified by the latitude and longitude of the southeast corner of each, and are divided into SE, SW, NE and NW quarters.)

			Location		
No.	Museum No.	Locality	Lat.	Long.	Quadrant
<i>S. clarkii clarkii</i> —LOWER MAINLAND					
1	BC53-282A	Brunette River	49°	122°	SW
* 2	BC54-342	Chilliwack area	49°	121°	SW
* 3	BC54-343	Salmon River	49°	122°	SW
* 4	BC54-345	Phyllis Lake, Capilano watershed	49°	123°	NE
5	BC54-408	Brunette River, above Brunette St.	49°	122°	SW
* 6	BC54-426	Lane Cr., Mission, below CPR tracks	49°	122°	SE
7	BC54-498	Stave Lake	49°	122°	SE
8	BC55-303	Salmon River	49°	122°	SW
* 9	BC55-306	Fraser R. opposite Coquihalla at Hope	49°	121°	SE
10	BC55-313	Edwards Cr., mouth Hatzic Lake	49°	122°	SE
11	BC55-314	Edwards Cr., 1 mile above Hatzic L.	49°	122°	SE
12	BC55-323	Between Mission and New Westminster	49°	122°	SE
* 13	BC56-44	Fraser River, Fish Wheel, Hope	49°	121°	SE
* 14	BC56-87	Matsqui area Cr., crossing Abbotsford Mission Rd.	49°	122°	SE
15	BC56-120	Edwards Cr., Hatzic Lake	49°	122°	SE
16	BC56-121	Edwards Cr., which flows into west side Hatzic Lake	49°	122°	SE
17	BC56-551	Salmon River	49°	122°	SW
* 18	BC57-274	Pitt Lake	49°	122°	SW
20	BC57-403	Port John	52°	127°	SW
<i>S. c. clarkii</i> —LAKELSE LAKE AND NORTHERN B. C.					
* 21	BC55-326	Lakelse Lake, Fisheries Research Board weir	54°	128°	SW
* 22	BC56-453	One mile below Bulkey, Bulkey R.	55°	127°	SW
23	BC56-498	Winter Cr., 4 miles west of Telegraph Creek	57°	131°	NE
* 24	BC58-390	Lakelse Lake	54°	128°	SW
* 25	BC58-391	Lakelse Lake	54°	128°	SW
<i>S. c. clarkii</i> —VANCOUVER ISLAND					
26	BC53-257AA	Nile Creek	49°	124°	SW
27	BC56-52	Black Cr., Jordan R. area	49°	125°	NE
28	BC56-112	Inlet Cr. in a lake in Duncan area	48°	123°	NW
* 29	BC56-420	Courtney area, 12 miles south of Royston, Millard Creek	49°	125°	NE
30	BC57-24	Angus Cr., Nitinat River	49°	125°	SW
* 31	BC58-3	Alice Lake	50°	127°	SE
* 32	BC58-6	Keogh River	50°	127°	NE
* 33	BC58-8	Nine Mile Lake	50°	127°	NW
* 34	BC58-9	Rupert Inlet Lake	50°	127°	NW
* 35	BC58-10	Muir Lake, Keogh R. expansion	50°	127°	NE

S. c. lewisi—SOUTHEASTERN B. C.

36	BC54-339	Rosebud Lake, south of Salmo	49°	117°	SE
37	BC54-538	Rosebud Lake, south of Salmo	49°	117°	SE
*38	BC55-347	Crazy Cr., Eagle R., Kamloops area	50°	118°	NW
*39	BC55-351	Little Bull R., trib. of Kootenay R.	49°	115°	SE
40	BC56-49	Elkan R., trib. Upper Elk R., Kootenay area	49°	115°	SE
41	BC56-187	Lower Arrow Lake	49°	118°	NE
42	BC56-195	Rosebud Lake, South of Salmo	49°	117°	SE
*43	BC57-327	Sage Cr., trib. Flathead River	49°	114°	SE

APPENDIX TABLE B. Number of scales in the anterior region of the body (as defined on page 907; see also Fig. 3).

Museum No.	No. of fish	Range	Mean	Median	Standard deviation
VANCOUVER ISLAND					
BC56-420	6	81-83	82.1	82	1.25
BC58-3	2	83-84	83.5	83.5	0.17
BC58-6	9	80-87	82.8	82	4.49
BC58-8	2	81-84	82.5	82.5	1.42
BC58-10	12	79-91	83.2	82.5	3.51
Total	31	79-91	82.9	82	2.71
LAKELSE LAKE AND NORTHERN B. C.					
BC55-326	15	80-87	82.8	83	1.68
BC58-390	2	83-83	83.0	83	...
BC58-391	5	79-84	82.0	83	1.79
Total	22	79-87	82.6	83	1.96
LOWER MAINLAND					
BC54-342	6	71-81	78.0	79	3.32
BC54-343	4	76-82	79.0	79	2.12
BC54-345	4	77-86	80.5	79.5	3.36
BC54-426	4	78-84	80.0	79	2.35
BC55-306	6	74-84	79.1	79.5	3.14
BC56-44	3	77-84	81.0	82	2.94
BC57-274	3	83-84	83.6	84	1.16
Total	30	71-86	79.8	79.5	3.28
Total <i>clarkii</i>	83	71-91	81.7	82	3.09
SOUTHEASTERN B. C.					
BC55-347	25	88-103	92.8	92	2.85
BC55-351	15	81-91	87.0	87	2.83
BC57-327	20	86-100	92.0	91	3.45
TOTAL <i>lewisi</i>	60	81-103	91.1	91	3.47

APPENDIX TABLE C. Number of scales from insertion of anal fin to lateral line in 83 *S. c. clarkii* and 60 *S. c. lewisi*.

Museum No.	No. of fish	Range	Mean	Median	Standard deviation
VANCOUVER ISLAND					
BC56-420	6	18-20	18.3	18	0.24
BC58-3	2	18-20	19.0	19	1.00
BC58-6	9	16-20	17.8	18	1.24
BC58-8	2	20-21	20.5	20.5	0.15
BC58-10	11	12-20	17.7	18	2.16
Total	30	12-21	18.2	18	1.64
LAKELSE LAKE AND NORTHERN B. C.					
BC55-326	11	16-18	16.5	16	1.41
BC58-390	2	18-19	18.5	18.5	0.17
BC58-391	10	15-20	17.3	17	1.47
Total	23	15-20	17.0	17	1.75
LOWER MAINLAND					
BC54-342	6	14-19	16.8	17	1.61
BC54-343	4	16-18	17.0	17	0.23
BC54-345	4	16-18	17.2	17.5	0.26
BC54-426	4	17-19	18.2	18.5	0.26
BC55-306	6	16-18	17.3	17.5	0.26
BC56-44	3	17-18	17.3	17	0.18
BC57-274	3	18-18	18.0	18	...
Total	30	14-19	17.3	17.5	1.20
Total <i>clarkii</i>	83	12-21	17.5	18	1.52
SOUTHEASTERN B. C.					
BC55-347	25	21-25	22.5	22	1.24
BC55-351	15	17-21	19.3	19	1.13
BC57-327	20	20-25	22.9	23	1.66
TOTAL <i>lewisi</i>	60	17-25	21.8	22	2.08

APPENDIX TABLE D. Number of vertebrae, their range, mean, median, and standard deviation, in 75 specimens of *S. c. clarkii* and 65 specimens of *S. c. lewisi*.

Museum No.	No. of fish	Range	Mean	Median	Standard deviation
VANCOUVER ISLAND					
BC56-420	5	60-63	61.0	60	1.27
BC58-3	2	61-61	61.0	61	0
BC58-6	9	61-63	61.5	61	1.08
BC58-8	2	62-63	62.5	62.5	0.17
BC58-9	1	61	...	...	...
BC58-10	13	60-62	61.2	61	0.20
Total	32	60-63	61.3	61	1.06
LAKELSE LAKE					
BC55-326	17	60-63	61.3	61	0.38
BC56-453	1	61	...	...	...
BC58-390	2	61-61	61.0	61	0
BC58-391	17	61-64	61.5	61	0.27
Total	37	60-64	61.4	61	1.13
LOWER MAINLAND					
BC56-87	6	60-62	61.0	61	0.18
Total <i>clarkii</i>	75	60-64	61.3	61	1.21
SOUTHEASTERN B. C.					
BC55-347	25	60-63	61.2	61	0.20
BC55-351	15	60-63	61.1	61	0.28
BC57-327	25	60-64	61.1	61	0.30
Total <i>lewisi</i>	65	60-64	61.1	61	0.28

Total 36 3-176 68.11 56.5 33.89 8-100 43.13 37 22.16 4-53 17.69 15 10.87 4-44 14.75 13.5 8.79

LOWER MAINLAND

BC53-282A	2	38-66	52.0	52	17.21	22-32	27.0	27	5.0	9-15	12.0	12	3.00	16-17	16.5	16.5	0.71
BC54-343	8	17-101	50.37	44	17.79	13-58	25.0	17.5	14.04	3-25	11.0	9.5	6.82	5-23	12.87	11	6.02
BC54-345	3	73-111	95.0	101	16.08	52-70	59.3	56	8.58	15-23	18.3	17	3.54	17-22	20.0	21	2.16
BC54-408	1	15	...	...	...	12	...	...	...	3	...	...	...	6	...	...	...
BC54-426	7	24-69	41.14	37	13.78	10-37	23.57	24	8.36	5-13	8.4	8	2.37	6-12	8.71	9	1.9
BC54-498	1	106	...	...	...	80	...	...	...	19	...	...	...	24	...	...	...
BC55-303	4	44-83	59.7	56	15.1	23-38	30.5	30.5	5.7	10-13	11.75	12	1.1	12-16	14.0	13	1.42
BC55-306	3	46-89	65.3	61	17.84	22-56	34.33	25	15.38	9-19	12.66	10	14.8	13-29	18.33	13	7.62
BC55-313	1	89	...	...	...	52	...	...	...	18	...	...	...	17	...	...	...
BC55-314	2	40-41	40.5	40.5	0.56	18-26	22.0	22	4.0	7-9	8.0	8	...	9-11	10.0	10	1.0
BC55-323	3	41-120	76.0	67	32.82	22-35	25.66	22	6.93	8-15	10.0	8	3.55	13-18	15.33	15	2.31
BC56-44	4	10-30	19.7	19.5	8.2	2-12	8.5	10	3.92	0-5	1.75	1	2.05	0-11	6.0	6.5	4.07
BC56-87	4	20-48	36.0	38	10.28	9-29	20.5	22	7.53	4-9	6.5	6.5	2.51	9-13	11.5	12	1.68
BC56-120	1	2	...	...	...	2	...	...	...	1	...	...	...	2	...	...	...
BC56-121	1	53	...	...	...	30	...	...	...	12	...	...	...	14	...	...	...
BC56-551	1	67	...	...	...	38	...	...	...	17	...	...	...	21	...	...	...
BC57-403	1	49	...	...	...	41	...	...	...	12	...	...	...	13	...	...	...
Total	47	2-120	51.65	46	26.71	2-80	27.95	24	16.23	0-25	10.40	9	5.83	0-29	12.42	13	6.27

TOTAL <i>clarkii</i>	141	2-250	80.43	57	57.37	2-150	48.17	37	35.77	0-56	17.63	13	12.28	0-67	16.43	13	10.99
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SOUTHEASTERN B. C.

BC54-339	2	0-12	6.0	6	6.0	1-15	8.0	8	7.0	8-16	12.0	12	4.0	20-28	24.0	24	4.0
BC54-538	19	0-37	7.21	4	8.86	1-26	8.0	5	5.94	3-15	10.31	11	3.44	12-35	21.78	22	5.46
BC55-347	33	1-22	9.72	9	5.4	2-20	10.0	9	4.04	1-24	11.78	12	4.48	13-30	21.15	21	4.28
BC55-351	31	1-43	8.16	4	10.46	1-52	10.54	8	10.89	2-25	10.54	10	5.44	8-42	18.8	18	9.43
BC56-49	23	0-16	5.52	4	4.4	1-18	7.56	8	3.73	1-12	4.21	3	3.16	0-14	4.04	3	3.87
BC56-187	1	13	...	...	...	7	...	...	...	9	...	...	...	24	...	...	...
BC56-195	2	8-12	10.0	10	2.0	5-7	6.0	6	1.0	9-18	13.5	13.5	4.5	15-23	19.0	19	4.0
BC57-327	35	0-29	8.45	6	6.74	1-29	10.2	10	6.83	2-25	9.57	9	5.01	7-44	19.31	20	8.43
TOTAL <i>lewisii</i>	146	0-43	8.00	6	7.52	1-52	9.42	8	6.99	1-25	9.61	10	5.15	0-44	17.63	18	9.09

APPENDIX TABLE F. Number of spots on the cheek, their range, mean, median, and standard deviation, of 60 specimens of *S. c. clarkii* and 98 specimens of *S. c. lewisi*.

Museum No.	No. of fish	Range	Mean	Median	Standard deviation
VANCOUVER ISLAND					
BC56-420	2	16-17	16.5	16.5	0.56
BC58-3	2	38-66	52.0	52	14.0
BC58-6	10	10-54	30.2	32	12.60
BC58-8	2	39-45	42.0	42	3.75
BC58-9	1	45	...	...	...
BC58-10	13	15-57	35.5	33	9.55
Total	30	10-66	34.3	34.5	12.7
LAKELSE LAKE AND NORTHERN B. C.					
BC55-326	11	11-32	17.8	18	5.47
BC58-390	2	16-27	21.5	21.5	5.51
BC58-391	17	8-30	16.9	15	5.84
Total	30	8-32	17.5	16.5	5.79
TOTAL <i>clarkii</i>	60	8-66	25.9	20	12.94
SOUTHEASTERN B. C.					
BC55-347	33	1-8	3.8	4	1.66
BC55-351	31	1-11	4.9	5	2.29
BC57-327	34	2-12	5.9	6	2.22
TOTAL <i>lewisi</i>	98	1-12	4.8	4.5	2.25

Maximum Depth and Average Depth of Lakes¹

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ABSTRACT

By considering data of maximum depth and average depth for 107 lakes, it is suggested that an 'elliptic sinusoid' closely approximates the average shape of lake beds. The elliptic sinusoid is defined as a geometric body whose base is an ellipse such that planes perpendicular to the base ellipse passing through the centre of the latter intersect the surface of the body along troughs of sine curves. The results are capable of practical application.

INTRODUCTION

IN CONNECTION WITH A PROBLEM in limnology, I was interested to see if there is any straightforward relationship between the average depth and the maximum depth of lakes. Relevant data were available for 107 lakes situated in various parts of the world and at varying altitudes (Table I). Surprisingly enough, a plot of the data (Fig. 1) indicated an approximately linear relationship with but a moderate scatter about the straight line of best fit calculated from least squares. The average depth of lakes appears to be about half as great as their maximum depth, or to be more precise, the ratio \bar{D}/D_m (\bar{D} = average depth, D_m = maximum depth) works out at 0.467. The average depth \bar{D} is, of course, defined as V/A (V = volume, A = surface area):

AVERAGE SHAPE OF LAKE BEDS

It is worth reflecting on the implications for the shape of lake beds of the value 0.467 for the ratio \bar{D}/D_m . If lakes had the shape of rectangular parallelepipeds, the ratio would be 1 and it is readily shown that for elliptic paraboloids and right elliptic cones, the ratios would work out as $\frac{1}{2}$ and $\frac{1}{3}$, respectively. The observed ratio is thus near the value of the ratio for elliptic paraboloids. However, the elliptic sinusoid (see Fig. 2) seems to be a more successful idealization of the average form of lake-bed shapes found in nature: the lake surface is an ellipse ('base ellipse'), the lake bed is a 'sinusoid'. The sinusoidal lake bed can be defined as such that vertical planes passing through the centre of the base ellipse (lake surface) intersect the lake bed along the troughs of sine curves.

The volume, V , of such an elliptic sinusoid is found to be (see Appendix)

$$4\left(1 - \frac{2}{\pi}\right)abD_m = 1.456.. abD_m \quad (1)$$

In (1) a and b are the half-axes of the base ellipse, or lake surface ellipse, and, as

¹Received for publication April 16, 1959.

TABLE I. Geographical region, name, average depth and maximum depth of lakes.

Lake	Avg. depth (m)	Max. depth (m)	Lake	Avg. depth (m)	Max. depth (m)	Lake	Avg. depth (m)	Max. depth (m)
ARCTIC			BRITAIN			CENTRAL EUROPE, ALPS (cont.)		
Anneks Sø	45	90	Ness	133	238	Annecy	41.5	80.6
Chandler	13.5	21	Garry	24	65	Orta	71.3	143
SCANDINAVIAN PENINSULA AND FINLAND			Lochy	70	162	Bourget	81	145
Tennesvatn	93	168	Morar	87	310	Aiguebelette	30.6	71.1
Eikesdalsvatn	83	155	Katrine	61	151	Bolsena	78	146
Hornindalsvatn	237.2	514	Windermere			EASTERN AND CENTRAL U.S.A.		
Strynsvatn	130	209	1. North basin	26	67	Green	33.1	72.3
Loenvatn	68.9	132	2. South basin	17.7	44	Geneva, Wisc.	19.7	49.3
Oldenvatn	42.6	92	NORTHERN CONTINENTAL EUROPE			Mendota	12.1	25.6
Breimsvatn	130.4	278	Beloye	4.2	13.5	Skaneateles	43.5	90.5
Lemonsjoen	15	45	Furesø	12.3	36	Owasco	29.3	54
Bessvatn	30	102	Marien	4.9	11	Canandaigua	38.8	83.5
Feforvatn	19	54	Hemmelsdorfer	5.5	44.5	Cayuga	54.5	132.6
Flakevatn	30	75	Dratzig	20	83	Seneca	88.6	188.4
Mjøsa	187	449	Müritz	6.3	33	Keuka	30.5	55.8
Evangervatn	46	107	Madü	18.7	42	Plew	7.3	18.6
Vangsvatn	37	60	Arend	29.7	49.5	Yellow Creek	10.6	22
Ladoga	56	223	Pulvermaar	37.6	74	Big Barbee	6.7	15
Holsfjord	114	295	Schalken-mehrenmaar	11.4	21	Silver	4.1	10.4
Eikeren	94	154	CENTRAL EUROPE, ALPS			Manitou	3	14.8
Vettern	39	119	Blanc	22.9	58.7	WESTERN U.S.A.		
Klämningen			Gérardmer	16.9	36.2	Pyramid	57	104
1. Klövsta basin	16.3	37	Lunzer Untersee	19.8	33.7	Tahoe	249	501
2. Central basin	5	11	Atter	84.2	170.6	Mead	13.7	58.6
3. Laxne basin	16.2	29	Gmündener	89.7	197	JORDAN VALLEY		
NORTHWESTERN CANADA AND ALASKA			Tegern	40	71	Hula	1.7	4
Great Slave	62	614	Schlier	24.9	37	Galilee		
Karluk	48.6	126	Staffel	10.7	40	(Tiberias)	24	50
WESTERN CANADA			Kochel	28.5	65	Dead Sea		
Waskesiu	11.1	24	Constance	90	252	1. North basin	185	400
Kingsmere	21.2	47	Walchen	79.3	196	2. South basin	6.4	11
Amethyst,			Hallstätter	64.9	125.2	HIGH SOUTH CENTRAL ASIA		
South basin	9.7	21	Greifen	17	34	Panggong Tso	26.1	50
Maligne	40.5	96	Zürich	44	143	Manasarovar	49.5	81.8
Bow	17.6	48	Walén	103	151	CENTRAL AMERICA		
Minnewanka	38.1	80	Zuger	84	198	Atitlan	183	341
Paul	34.2	56	Lucerne	104	214	Amatitlan	18.8	33.6
Okanagan	69.5	235	Thun	135	217.2	Güija	16.5	26
Cultus	32.2	42	Wörther	43.2	84.6	INDONESIA		
			Öschinen	34.6	56.6	Rana		
			Geneva	154.4	310	Klindungan	90	134
			Nantua	28.4	43			
			Como	185	410			
			Lugano	130	288			

before, D_m is the maximum depth of the lake. Since the area of the lake surface ellipse concerned is πab , $\bar{D} = V/A = 0.464 D_m$, so that the ratio $\bar{D}/D_m = 0.464$. The latter value is very close to the value for the ratio (0.467) observed in nature.

PRACTICAL APPLICATION

One useful implication of the sinusoidal profile described above is that in any vertical cross section through the centre of the lake surface ellipse we should find one half of the maximum depth of the lake reached at two points which are

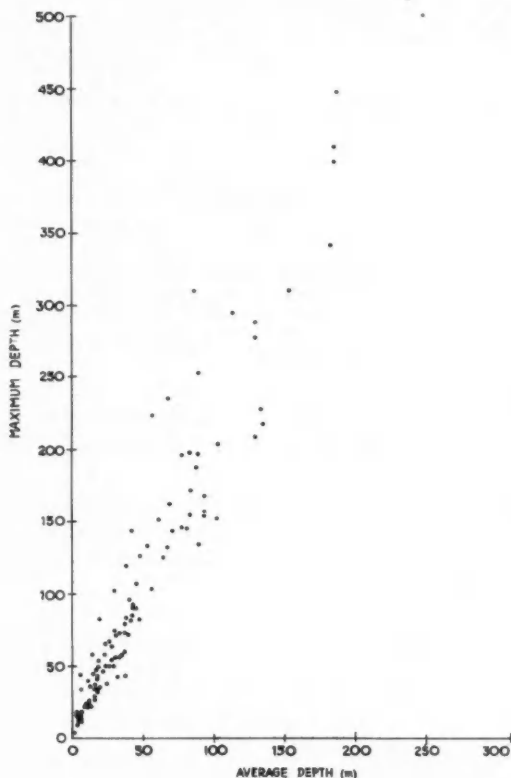


FIG. 1. Maximum depth plotted against average depth for 107 lakes.

situated at distances equal to one sixth of the total width of the lake along the cross section in question from the respective shore points. In terms of Fig. 2,

$$DD' = EE' = \frac{1}{2} BB', \quad AE = DC = \frac{1}{6} AC.$$

The above (idealized) characteristic of lake-bed shapes may be of considerable help whenever a quick survey of a lake is desired for obtaining ap-

proximate figures for the average and maximum depths. Unless the lake bed is very irregular, the following abridged procedure is likely to prove useful. Consider the two main axes of the lake surface ellipse. At points one sixth of the width of the lake along these axes, take soundings of the depth. Call the average

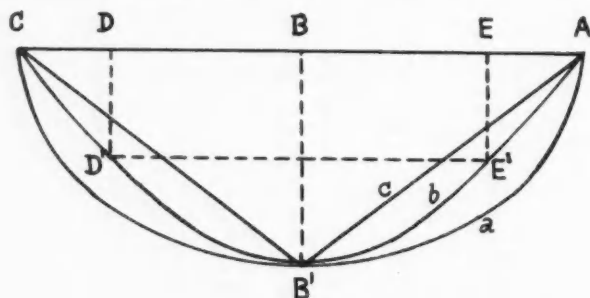


FIG. 2. Vertical cross-sections through three lake bed "shapes": (a) half an ellipsoid of revolution; (b) elliptic sinusoid; (c) right elliptic cone. It is assumed that the surface of the lake is of an elliptic form and that the cross-sections in the diagram pass through the centre of that ellipse.

of the four measured depths \bar{D}^* . Then, a first approximation to the true maximum depth is $2\bar{D}^*$; a first approximation to the true average depth will be $0.467 \times 2\bar{D}^*$, or $0.93 \bar{D}^*$.

As an example for the above, we shall cite the case of the Sea of Galilee in the Jordan Rift. The two 'main' axes of the Sea of Galilee are as specified in the table below. By applying the procedure described in the foregoing paragraph, we arrive at the following results:

Cross Section	'One-sixth Depth' (meters)
010° to 190°	In north 19.5
	In south 27
280° to 100°	In west 17
	In east 37
	Average 25.1

We thus estimate the maximum depth to be about 50 m and the average depth about 23 m. The correct values are 50 m and 24 m, respectively.

ACKNOWLEDGMENT

The writer is pleased to record his indebtedness to Prof. G. E. Hutchinson, Osborn Zoological Laboratory, Yale University, New Haven, Conn., for a list of data on lakes.

APPENDIX. Calculation of the volume of an elliptic sinusoid.

Let $z = f(x, y)$ be the equation of the surface of the elliptic sinusoid. A sketch of the sinusoid will show that:

$$z = D_m \cos \frac{\pi}{2} \left(\frac{x^2 + y^2}{\xi^2 + \eta^2} \right)^{\frac{1}{2}} \quad (2)$$

where ξ and η are, respectively, the x and y coordinates of the base ellipse (= elliptic circumference of lake surface). If a and b are the half-axes of that base ellipse, then:

$$\frac{\xi^2}{a^2} + \frac{\eta^2}{b^2} = 1 \quad (3)$$

so that from (2) and (3) and since $x/\xi = y/\eta$:

$$z = D_m \cos \frac{\pi}{2} \left(\frac{x^2}{a^2} + \frac{y^2}{b^2} \right)^{\frac{1}{2}} \quad (4)$$

Now, the volume, V , is:

$$V = 4 \int_{y=0}^b \int_{x=0}^a z \, dx \, dy = 4 D_m \int_{y=0}^b \int_{x=0}^a \cos \frac{\pi}{2} \left(\frac{x^2}{a^2} + \frac{y^2}{b^2} \right)^{\frac{1}{2}} dx \, dy \quad (5)$$

Introducing polar coordinates into (5) and integrating, we find that

$$V = 4 \left(1 - \frac{2}{\pi} \right) ab D_m,$$

as stated in the paper.

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CORRECTIONS FOR RECENT PUBLICATIONS OF THE
FISHERIES RESEARCH BOARD OF CANADA

Journal of the Fisheries Research Board of Canada

VOLUME 14, No. 1—paper by D. E. Sergeant and H. D. Fisher: "THE SMALLER CETACEA OF EASTERN CANADA."

Page 89: Figure 3A is inverted.

Page 101: Table IV, year 1948, under "Pilot whale (*G. melaena*)" — for "15" read "209".

Page 103: Line 9, re "... two almost certain pilot whales ..." subsequent information indicates these were more likely minke whales (*Balaenoptera acutorostrata*).

Page 103: Line 11, for "Hebron Fjord" read "Battle Harbour". There is thus no evidence for the occurrence of *Illex* or *Globicephala* north of Hamilton Inlet Bank on the Labrador coast.

Page 103: New para. 1, line 7, for "15" read "209".

Page 109: New para. 3, lines 7-8, "maxillae" and "premaxillae" should be transposed.

Page 109: New para. 4, line 5, for "W. B. Schevill" read "W. E. Schevill".

VOLUME 15, No. 2—paper by I. A. McLaren: "SOME ASPECTS OF GROWTH AND REPRODUCTION OF THE BEARDED SEAL, *Erignathus barbatus* (ERXLEBEN)."

Page 218, temperatures for May 17, 1957, in Appendix Table: for "12.2" read "6.7" (for all three depths).

VOLUME 15, No. 4—paper by Edgar C. Black: "HYPERACTIVITY AS A LETHAL FACTOR IN FISH."

Pages 579 and 580: In Fig. 1 and 2 the scales are incorrectly drawn in some respects. Corrected versions of these Figures are given in the paper by Black *et al.*, *J. Fish. Res. Bd. Canada*, Vol. 16, No. 4, pages 396 and 397.

VOLUME 15, No. 6—paper by A. C. Kohler and J. R. Clark: "HADDOCK SCALE-OTOLITH COMPARISONS."

All χ^2 values in this paper are somewhat too large because in computing them the observed rather than expected values were used in the divisors. The correct form of the example given on the last line of page 1242 is as follows:

$$\chi^2 = \frac{(24-21)^2}{21} + \frac{(18-21)^2}{21} = 0.857$$

However, using the correct formula does not seriously reduce the χ^2 figures tabulated in Tables IV and V. In only one instance is one of the "Probabilities" shifted from significant to non-significant at the 0.05 level: this is in line 6 of Table V, where 0.05 becomes 0.06.

VOLUME 16, No. 1—paper by E. Gordon Young *et al.*: "THE CHEMICAL COMPOSITION OF SEA WATER IN THE VICINITY OF THE ATLANTIC PROVINCES OF CANADA."

Page 7: 2nd last line, instead of "Sable Island" read "Cape Sable Island".

VOLUME 16, No. 2—paper by D. R. Idler and I. Bitners: "BIOCHEMICAL STUDIES ON SOCKEYE SALMON DURING SPAWNING MIGRATION. V. CHOLESTEROL, FAT, PROTEIN AND WATER IN THE BODY OF THE STANDARD FISH."

Page 235: Para. 1, line 3, "1135-km" should read "1152-km".

VOLUME 16, No. 3—paper by Steinar Olsen: "MESH SELECTION IN HERRING GILL NETS."

Page 346, heading for Column 10 of Table II: for " ${}_cN_i$ " read " ${}_cN'_i$ ".

VOLUME 16, No. 3—paper by Joe Hoy: "A PORTABLE CONDUCTIVITY BRIDGE FOR FIELD USE."

Page 382: In Figure 3 for "T2—Hammond 142Q transformer" read "T2—Hammond 142M transformer".

VOLUME 16, No. 4—paper by E. H. Grainger and J. G. Hunter: "STATION LIST OF THE 1955–58 FIELD INVESTIGATIONS OF THE ARCTIC UNIT OF THE FISHERIES RESEARCH BOARD OF CANADA."

Page 410: Table II, Station 58–1003 — under North Latitude — for "63° 45'25" read "63° 43'25" .

VOLUME 16, No. 4—paper by Vera M. Creelman and Neil Tomlinson: "BIOCHEMICAL STUDIES ON SOCKEYE SALMON DURING SPAWNING MIGRATION. VI. RIBONUCLEIC ACID AND DEOXYRIBONUCLEIC ACID."

Page 427: Table III, line 5 ("Gonads"), the values "1.24", "1.00", "1.39" and "0.98" for C, A, G, and U under "Forfar Creek" should read "1.18", "1.00", "1.32", and "0.93" respectively.

Page 427: 5th reference, "GUSTAVSON" should read "GUSTAFSON".

VOLUME 16, No. 4—paper by A. H. Leim and L. R. Day: "RECORDS OF UNCOMMON AND UNUSUAL FISHES FROM EASTERN CANADIAN WATERS, 1950–58."

Page 503: In the Abstract, line 4, instead of "*(Prionotus evolans)*" read "*(Prionotus evolans)*".

VOLUME 16, No. 4—paper by L. S. Berg: "VERNAL AND HIEMAL RACES AMONG ANADROMOUS FISHES."

In the Translator's Preface, page 515, paragraph 2, line 6: instead of "Driagin", read "Gerbilsky". Dr J. W. Atz has drawn to the translator's attention the fact that Professor Gerbilsky, in more recent papers, has indentified the autumn run (Group IV) of *Acipenser gildenstädti* in the Kura River as a vernal race.

VOLUME 16, No. 4—paper by D. R. Idler and H. Tsuyuki: "BIOCHEMICAL STUDIES ON SOCKEYE SALMON DURING SPAWNING MIGRATION. VIII. ANDROGEN CONTENT OF TESTES."

Page 559: Para. 1, line 3, "1,135-km" should read "1,152-km".

Bulletins of the Fisheries Research Board of Canada

BULLETIN No. 119, by W. E. Ricker: "HANDBOOK OF COMPUTATIONS FOR BIOLOGICAL STATISTICS OF FISH POPULATIONS."

Page 72, Section 2G, 1st paragraph, 2nd and 3rd line from the bottom: instead of " $dF/dl = -i'k$ ", read " $dF/dt = -i'k$ ".

Page 154, legend for Figure 6.2, 2nd line: instead of "millions of pounds", read "thousands of pounds".

Page 245, 5th line from the bottom: instead of "by dotted lines", read "by open circles".

Page 271: for the value of i corresponding to $a = 0.50$, instead of "0.6391" read "0.6931".

Progress Reports of the Pacific Coast Stations of the Fisheries Research Board of Canada

ISSUE No. 113—Article by B. E. March *et al.*: "THE USE OF CONDENSED HERRING SOLUBLES IN TURKEY POULT RATIONS."

Page 4, 5th last value in right-hand column of Table II: for "2220" read "2200".

Ac

Ac

Ac

Ac

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Ag

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Ar

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Ar

INDEX TO VOLUME 16 OF THE JOURNAL OF THE FISHERIES RESEARCH BOARD OF CANADA

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- 6: 853 (pink and chum salmon)

Fertilizers

- 6: 887 (used on P.E.I. farms)

Fillets

- 1: 1 (preservation with CTC antibiotic in tropics)
- 1: 13, 21 (cod, haddock; odours caused by *Pseudomonas* and other bacteria)
- 1: 33, 43, 53, 63 (chemical structure of protein)
- 1: 63 (analysis for extractives in cod)
- 2: 223 (cod, seasonal analysis for TMA)
- 5: 747 (proteolysis in cod)
- 5: 755 (lipase activity in lingcod)

Fiords (see Inlets)

Fisher, Harold Dean

- 6: 929 (corrections for Cetacea paper)

Fisheries

- 1: 107, 131 (Lake Winnipeg)

Fishes (see also Distribution)

- 4: 503 (distribution in Atlantic)
- 6: 807 (Miramichi R. and estuary)
- 6: 838 (Hooknose Creek, B. C.)

Fishing methods

- 1: 95 (effects of trolling on salmon)
- 1: 131 (setting gill nets under ice)

Flavour (see Quality; Test, freshness)

Flesh (see also Amino acids; Analysis; Protein; Quality)

- 4: 449 (abnormal pigmentation of cod and haddock)

Flounder, fourspot (*Paralichthys oblongus*)

- 4: 503 (first Canadian record)

Flow, volume of

- 6: 835 (in relation to salmon migration)

Fluorine

- 1: 7 (in Atlantic coastal sea water)

Food

- 3: 269 (of trout in Paul L.)
- 3: 321 (of hatchery trout)

Food supply

- 3: 283 (of herring in Barkley Sound)

Forbes, Francis Duncan

- 4: 391 (changes in blood of trout following exercise)

Fougère, Henri

- 5: 747 (salt effect on proteolysis of cod muscle)

Foxe Basin

- 4: 453 (oceanography at Igloolik)

Fraser, Doris Isabel

- 1: 43 (lipid hydrolysis in fish muscle)

Fraser River, B.C.

- 2: 235 (biochemistry of sockeye salmon during spawning migration)

- 4: 421, 559 (biochemistry of sockeye salmon during spawning migration)

Freshness (see Quality; Test, freshness)

Fry migration

- 6: 857 (salmon in Hooknose Creek, B.C.)

G

Gelatin

- 4: 561 (in herring solubles)
- 5: 685 (in herring, etc. solubles)

Gill nets

- 1: 131 (method of setting under ice)
- 1: 143 (cotton and nylon, L. Winnipeg)
- 3: 339 (mesh selection, herring)

Glycogen

- 3: 321 (reserves in hatchery trout)

Godfrey, Harold

- 3: 329 (average weights of pink salmon)
- 4: 553 (average weights of chum salmon)

Goldfish (*Carassius auratus*)

- 1: 121 (growth at different salinities)
- 2: 175 (respiration)

Grainger, Edward Henry

- 4: 403 (station list of Arctic investigations, 1955-58)
- 4: 453 (annual oceanographic cycle at Igloolik, N.W.T.)
- 6: 930 (correction)

Greenough, Maxine Frances

- 1: 13, 21 (odours from action of *Pseudomonas* on fish muscle)
- 2: 223 (seasonal variation in landed quality of cod and haddock)
- 4: 539 (factors affecting use of nitrite preservative for fish flesh)

Growth

- 1: 121 (of fish, related to salinity)
- 3: 269 (rainbow trout in Paul L.)
- 5: 721 (calculation of, in fishes)

Gulf of Alaska

- 3: 351 (*Chaetognatha* in)
- 3: 383 (fishes taken in)
- 6: 795 (*Sagitta lyra* distribution)

Gulf of St. Lawrence

- 2: 213 (nematodes in cod fillets)

H

Haddock (*Melanogrammus aeglefinus*) (biology)

- 3: 386 (correction)

- 4: 449 (red flesh in)

- 6: 929 (correction)

Haddock (technology)

- 1: 13, 21 (odours caused by *Pseudomonas* and other bacteria on flesh)

- 4: 449 (atypical flesh pigmentation)

- 4: 539 (nitrite treatment of fillets)

Halfbeak (*Hyporhamphus unifasciatus*)

- 4: 503 (first Canadian record)

Halibut, Atlantic (*Hippoglossus hippoglossus*) (technology)

- 1: 43 (lipid hydrolysis in frozen fillets)

Hallam, Jack Charles

- 2: 147 (habitat of 4 species of Ontario stream fish)

Halocline (see Density; Salinity)

Hanslip, Arthur

- 4: 391 (changes in blood of trout following exercise)

Hartman, Gordon Frederick

- 5: 695 (homing of rainbow trout)

Herring, Atlantic (*Clupea harengus*)

- 3: 339 (size selection by gill nets)

- 3: 386 (correction)

Herring, Pacific (*Clupea pallasii*) (biology)

- 3: 283 (distribution of juvenile)

- 3: 309 (juvenile and adult populations)

Herring, Pacific (technology)

- 4: 561 (solubles, viscosity of)

- 5: 679 (seasonal proximate analyses)

- 5: 685 (stickwater and condensed solubles)

Hewson, Leo Clare

- 1: 107 (Lake Winnipeg whitefish fishery)

- 1: 131 (winter, fishery on Lake Winnipeg)

Hochachka, Peter William

- 3: 321 (diet, glycogen and fatigue in trout)

Homing

- 5: 695 (trout in Loon L.)

Hooknose Creek, King Island, B.C.

- 6: 835 (production of pink and chum salmon)

Hourston, Alan Stewart

- 3: 283 (distribution of juvenile herring)

- 3: 309 (relationship of juvenile to adult herring population)

Hoy, Joe

- 3: 381 (portable conductivity bridge)

- 6: 930 (conductivity bridge—correction)

Hunter, John Gerald

- 4: 403 (station list of Arctic investigations)
- 6: 835 (production of pink and chum salmon)
- 6: 930 (correction)

Hyperactivity

- 6: 929 (in fish—correction)

I

Ice, Arctic

- 4: 457 (in region of Igloolik, N.W.T.)

Ice-jigger

- 1: 135 (for setting nets under ice)

Idler, David Richard

- 2: 235 (biochemistry of sockeye salmon during spawning migration)
- 4: 559 (testicular androgen of sockeye salmon during spawning migration)
- 4: 561 (enzyme action on viscosity of whale solubles)
- 5: 679 (seasonal variation in fat, etc. of Pacific herring)

- 6: 930, 931 (corrections)

Igloolik (Canadian Arctic)

- 4: 453 (oceanographic cycles near)

Indicator species

- 6: 795 (*Sagitta*)

Indole

- 5: 747 (production in proteolysis of cod muscle)

Inlets, fiords, estuaries (see also Oceanography)

- 5: 635 (currents in Knight Inlet, B.C.)

Insolation

- 4: 457 (in Arctic at Igloolik, N.W.T.)

Invertebrates, freshwater

- 2: 147 (of Ontario streams)

Iodine

- 1: 7 (in Atlantic coastal sea water)

J

John Dory (*Zenopsis ocellata*)

- 4: 503 (Canadian records and illustration)

K

Kennedy, William Alexander

- 4: 389 (obituary of R. B. Miller)

Knight Inlet, B. C.

- 5: 635 (marine currents measurement in)

Kohler, Allan Carl

- 3: 386 (correction)
- 6: 929 (scale—otolith paper—correction)

Kokanee (*Oncorhynchus nerka*)

- 6: 897 (origin of Cultus Lake specimens)
- Kootenay Lake, B.C.
- 6: 897 (sources of kokanee eggs)

L

Lactic acid and lactate

- 1: 95 (in troll-caught salmon)
- 3: 321 (in fish blood, related to exercise)
- 4: 391 (changes in trout after exercise)
- 4: 429 (in troll-caught salmon)

Lakes

- 6: 923 (maximum and average depths)

Lamprey, river (*Lampetra fluviatilis*)

- 4: 515 (seasonal "races")

Landings

- 1: 107, 131 (L. Winnipeg fishes)
- 6: 807 (Miramichi Bay commercial fishes)

Langille, Winston Murray

- 1: 7 (composition of Atlantic coastal sea water)

- 6: 930 (correction)

Larkin, Peter Anthony

- 4: 429 (fatigue and mortality in troll-caught salmon)
- 5: 721 (concept of growth in fishes)

Larvae

- 6: 763 (redfish)

Lawler, George Herbert

- 6: 929 (correction)

LeBrasseur, Robin John

- 6: 795 (*Sagitta lyra* in the eastern Pacific)

Leim, Alexander Henry

- 4: 503 (unusual Canadian Atlantic fishes)
- 6: 930 (correction)

Leim, Alexander Henry, *et al.*

- 3: 386 (correction)

Life history

- 4: 453 (zooplankters at Igloolik)

Limnology, physical

- 1: 131 (L. Winnipeg, in winter)
- 6: 830 (Miramichi R. temperatures)
- 6: 835 (Hooknose Creek, B.C.)
- 6: 887 (dissolved phosphorous in Ellerslie Brook)
- 6: 923 (depth of lakes)
- 6: 929 (Heming L.—correction)

Lindsey, Casimir Charles

- 5: 695 (homing of rainbow trout)

Lingcod (*Ophiodon elongatus*)

- 3: 386 (correction)
- 5: 755 (lipase enzyme in flesh)

Lipase (see Acids, fatty; Enzyme; Fat)

Lipid (*see also* Acids, fatty; Cholesterol; Fat)
 1: 43 (hydrolysis in frozen fish filets)
 1: 63 (analysis for, in extractives from cod muscle)

Lockeport, N.S.

2: 213 (nematodes in cod filets)

Loon Lake, B.C.

5: 695 (homing of trout)

Mc and Mac

McBride, John Raymond

4: 561 (enzyme action on viscosity of whale solubles)
 5: 679 (seasonal variation in fat, etc. of Pacific herring)

McKenzie, Russel Alderson

6: 807 (fishes of Miramichi R. and estuary)

MacLeod, Robert Angus

4: 561 (enzyme action on viscosity of whale solubles)
 5: 679 (seasonal variation in fat, etc. of Pacific herring)
 5: 685 (preparation and properties of condensed fish solubles)

M

Magnesium

1: 7 (in Atlantic coastal sea water)

Malpeque Bay, P.E.I.

1: 7 (composition of sea water)

Margolis, Leo

3: 385 (corrections)

Marking and tagging

3: 247 (trout and shiners in Paul L.)
 3: 309 (herring, Barkley Sound)
 5: 695 (trout, Loon L.)

Martin, William Robert

2: 213 (incidence of nematodes in Atlantic cod filets)

Mayflies (Ephemeroptera)

2: 147 (in Ontario streams)

Medaka (*Oryzias latipes*)

3: 363 (bibliography)

Metabolism

2: 175 (in fish—active and resting)

Migration and movements

3: 247 (trout and shiners in Paul L.)
 3: 283 (herring in Barkley Sound)
 3: 309 ("homing" of herring)

Migration, spawning

2: 235 (of sockeye salmon, biochemical changes during)

4: 421, 559 (of sockeye salmon, biochemical changes during)

Miller, Richard Birnie

3: 321 (diet, glycogen and fatigue in trout)

3: 386 (correction)

4: 389 (obituary)

Mineral compounds

1: 7 (in Atlantic Ocean coastal waters)

Miramichi River and estuary, N.B.

6: 807 (list of fishes)

Molybdenum

1: 7 (in Atlantic coastal sea water)

Moorjani, Madhow Naraindas

1: 1 (antibiotic for holding freshwater fish products in tropics)

Morphology

6: 903 (of cutthroat trout)

Mortality

1: 95 (of troll-caught salmon)

4: 429 (of troll-caught salmon)

Mortality rate

1: 73 (errors in estimates of)

Moyer, Rudolph Henry

6: 791 (keeping quality of dogfish flesh)

Muscle (*see* Amino acids; Protein)

Myosin (*see* Actomyosin)

N

Neave, Ferris

3: 383 (fishes from waters off the British Columbia coast)

Nematoda

2: 213 (in cod filets)

Neumann, Jehuda

6: 923 (maximum and mean depth of lakes)

Newfoundland

3: 339 (herring gill-net selection)

6: 763 (redfish larvae)

Nickel

1: 7 (in Atlantic coastal sea water)

Nitrite, preservative

1: 13 (for cod and haddock filets)

4: 539 (factors affecting use with filets)

Northcote, Thomas Gordon

5: 695 (homing of rainbow trout)

O

Obituary

4: 387 (R. B. Miller)

Ocean survival

6: 880 (pink and chum salmon)

Oceanography, Arctic

- 4: 453 (chemical, physical, zooplankton cycle at Igloodik, N.W.T.)

Oceanography, Atlantic

- 1: 7 (chemical composition, Atlantic coastal water)
- 6: 830 (Miramichi estuary)
- 6: 930 (correction)

Oceanography, Pacific

- 3: 283 (Barkley Sound, B.C.)
- 3: 351 (Gulf of Alaska)
- 5: 565 (August 1955 features of NE Pacific)
- 5: 635 (current measurement in Knight Inlet)
- 6: 795 (related to distribution of *Sagitta lyra*)

Odense, Paul Holger

- 1: 53 (isolation of tropomyosin from cod muscle)

Odour (see also Quality; Test, freshness)

- 1: 13, 21 (caused by *Pseudomonas* and other bacteria on fish muscle)

Olsen, Steinar Johannes

- 3: 339 (mesh selection in herring gill nets)
- 6: 930 (correction)

Ontario

- 2: 147 (stream fish and invertebrates)

Ophicephalus ("Korva" and "Avalu") (India)

- 1: 1 (preservation of fillets with CTC antibiotic)

Organoleptic tests (see Quality; Test, freshness)

Organs

- 4: 421 (analyses of sockeye salmon)
- 4: 559 (analyses of sockeye salmon testes)
- 5: 679 (seasonal weights of Pacific herring gonads)

OTC (Oxytetracycline) (see Antibiotic; Quality)

Oxygen capacity

- 2: 175 (of blood of fish)

Oxygen concentration

- 2: 175 (effect on fish respiration)

Oxygen, dissolved (see also Limnology; Oceanography)

- 4: 463 (in Arctic sea water)

Oxytetracycline (OTC) (see Antibiotic; Quality)

Oysters

- 6: 887 (effect of farmland drainage on production)

P

Pacific Ocean (see also Oceanography, Pacific)

- 6: 795 (distribution of *Sagitta lyra*)

Parasites (of whales)

- 3: 385 (correction)

Parker, Robert Ray

- 1: 95 (fatigue in troll-caught salmon)
- 4: 429 (fatigue and mortality in troll-caught salmon)
- 5: 721 (concept of growth in fishes)

pH (see also Limnology; Oceanography)

- 1: 13, 21 (action on production of odours by fish-spoiling bacteria)
- 4: 391 (changes in trout after exercise)

Phosphate

- 1: 7 (in Atlantic coastal sea water)
- 4: 463 (in Arctic sea water near Igloodik, N.W.T.)

Phosphorus

- 4: 421 (in nucleic acids of migrating sockeye salmon)
- 6: 887 (in drainage waters)

Physics, of ocean water (see also Oceanography)

- 5: 565 (in NE Pacific during August 1955)

Pickard, George Lawson

- 5: 635 (current measurement in Knight Inlet, B.C.)

Pigment

- 4: 449 (atypical, in cod and haddock flesh)

Pike, Gordon Chesley

- 3: 385 (correction)

Pinnipedia

- 3: 385 (correction)

Plaice, American (*Hippoglossoides platessoides*) (technology)

- 1: 43 (lipid hydrolysis in frozen fillets)

Plectobranthus evides

- 5: 759 (first British Columbia record; illustration)

Population estimates

- 5: 695 (trout, Loon L.)

Population statistics

- 6: 931 (corrections for Handbook)

Potassium

- 1: 7 (in Atlantic coastal sea water)

Predation

- 3: 247, 269 (of trout on shiners)
- 6: 867 (of sculpins and cohoes on salmon fry)

Preservative (see also Quality)

- 1: 1 (CTC for fish and fillets in tropics)

- 1: 13 (antibiotics and nitrite, for cod and haddock fillets)
 4: 539 (nitrite for cod and haddock fillets)
 5: 685 (for stickwater and solubles)
 6: 791 (CTC for dogfish flesh)
- Prickleback, two-spotted (*Plectobranthus evides*)
 5: 759 (first British Columbia record)
- Protein (see also Actin; Actomyosin; Acids, amino; Tropomyosin)
 1: 21 (odour production by action of *Pseudomonas* and other bacteria)
 1: 33, 53 (chemical structure of cod-muscle)
 1: 43 (lipid hydrolysis in frozen fish)
 1: 63 (analysis for extractive from cod muscle)
 2: 235 (amounts in sockeye salmon during spawning migration)
 5: 679 (seasonal variation in amount, Pacific herring)
 5: 747 (proteolysis to amino acids, etc. in cod)
- Pseudomonas*
 1: 13, 21 (*fragi* et spp., producing odours in fish muscle)

Q

- Qadri, Sami Ullah
 6: 903 (subspecies of cutthroat trout)
- Quality (see also Test, freshness)
 1: 1 (CTC-treated freshwater fish in tropics)
 1: 13 (cod and haddock fillets)
 1: 21 (cod flesh)
 1: 43 (lipid hydrolysis in flesh)
 2: 223 (variation in cod landed seasonally)
 4: 555 (trimethylamine test for)
 5: 747 (cod fillets)
 5: 755 (lingcod fillets)
 6: 791 (dogfish flesh)

R

- Races, of fish
 4: 515 (vernal and hiemal)
- Redfish (*Sebastes marinus*) (biology)
 4: 503 (record specimen)
 6: 763 (pigmentation of larvae)
- Redfish (technology)
 1: 43 (lipid hydrolysis in frozen fillets)
- Refrigeration
 1: 43 (effect on lipid hydrolysis in fish flesh)

- 5: 755 (effect on lipase activity in lingcod fillets)

- 6: 791 (dogfish in chilled sea water)

Respiration

- 2: 175 (related to O_2 , CO_2 and temperature, in fishes)
 3: 321 (of trout after exercise)

Ribonucleic acid (see Acids, nucleic)

Ricker, William Edwin

- 4: 515 (translation of L. S. Berg paper)
 6: 897 (kokanee and residual sockeye)
 6: 930 (correction for preface of translation)
 6: 931 (corrections for Bulletin No. 119)

Rigor

- 1: 33 (in relation to chemical structure protein)

Rodgers, George Keith

- 5: 635 (current measurement in Knight Inlet, B.C.)

S

Sagitta (see Chaetognatha)

Salinity (see also Oceanography)

- 1: 121 (growth of fish related to)
 4: 462 (of Arctic water in relation to ice formation)
 5: 584 (of NE Pacific during August 1955)

Salmon, Atlantic (*Salmo salar*)

- 4: 515 (seasonal "races" in Europe)

Salmon, chinook (*Oncorhynchus tshawytscha*)

- 1: 95 (fatigue and mortality)
 1: 121 (size in New Zealand)
 4: 429 (fatigue and mortality in troll-caught)
 4: 515 (marking experiments of Rich and Holmes)
 5: 721 (growth computation)

Salmon, chum (*Oncorhynchus keta*)

- 1: 121 (growth at different salinities)
 4: 515 (summer and autumn runs on the Amur)
 4: 553 (average weight in British Columbia catches)

- 6: 835 (survival and production)

Salmon, coho (*Oncorhynchus kisutch*)

- 1: 121 (growth at different salinities)
 4: 429 (fatigue and mortality in troll-caught)
 6: 869 (consumption of salmon fry by)

Salmon eggs

- 3: 385, 386 (corrections)
 6: 835 (number in pinks and chums)

- Salmon, Pacific (biology)
 6: 800 (oceanic distribution, related to *Sagitta*)
- Salmon, pink (*Oncorhynchus gorbuscha*)
 1: 91 (3-year-old)
 3: 329 (variation in average weight in British Columbia)
 6: 835 (survival and production)
- Salmon, sockeye (*Oncorhynchus nerka*) (biology)
 1: 121 (growth at different salinities)
 2: 235 (biochemical changes during spawning migration)
 4: 421 (biochemical changes in organs during spawning migration)
 4: 559 (biochemical changes in testes during spawning migration)
 6: 897 ("residual" type)
 6: 930 (analysis—correction)
 6: 930, 931 (corrections)
- Sandeman, Edward John
 6: 763 (caudal pigmentation of redfish larvae)
- Sauger (*Stizostedion canadense*)
 1: 131 (L. Winnipeg catches, C/E, and size)
- Scales
 6: 903 (number on cutthroat trout)
- Scope for activity
 2: 175 (in fish)
- Scott, David Maxwell
 2: 213 (incidence of nematodes in cod fillets)
- Sculpin (*Cottus bairdi*)
 2: 147 (occurrence and associates in Ontario)
- Sculpin, prickly (*Cottus asper*)
 6: 867 (consumption of salmon fry)
- Sea robin, striped (*Prionotus evolvens*)
 4: 503 (first Canadian record)
- Seal, grey (*Halichoerus grypus*)
 3: 385 (correction)
- Seal, harbour (*Phoca vitulina*)
 2: 213 (in relation to cod nematodes)
- Seal, harp (*Phoca groenlandica*)
 2: 213 (in relation to cod nematodes)
- Selection
 6: 930 (of herring by gill nets—correction)
- Sergeant, David Ernest
 6: 929 (corrections for Cetacea paper)
- Shewan, James Mackay
 4: 555 (trimethylamine test in grading fish quality)
- Shiner, redbreast (*Leuciscus balteatus*)
 3: 247 (movements in Paul L.)
- Silicon
 1: 7 (in Atlantic coastal sea water)
- Sinclair, Alexander Campbell
 3: 321 (diet, glycogen and fatigue in trout)
- Size
 1: 107, 131 (L. Winnipeg fishes)
 3: 329 (average weight of pink salmon)
 4: 553 (average weight of chum salmon)
- Skeena River, B.C.
 1: 91 (3-year-old pink salmon)
- Smith, Donald Gilbert
 1: 7 (composition of Atlantic coastal sea water)
 6: 930 (correction)
- Smith, Morden Whitney
 6: 887 (phosphorus enrichment from farm lands)
- Sodium
 1: 7 (in Atlantic coastal sea water)
- Solubles, condensed
 4: 561 (herring and whale, viscosity and enzyme treatment of)
 5: 685 (production and properties, herring, etc.)
- Southcott, Burnett Anne
 6: 791 (keeping quality of dogfish flesh)
- Spawning
 6: 835 (of salmon in Hooknose Creek)
- Spawning grounds
 3: 283 (herring in Barkley Sound)
- Spawning migration (see Migration, spawning)
- Spoilage (see Test, freshness; Quality)
- Squairetail (*Tetragonurus cuvieri*)
 3: 383 (first Canadian record)
- Station list
 4: 403 (1955–58 Arctic investigations)
 6: 930 (Arctic investigations—correction)
- Statistics, catch (see Landings)
- Stickwater (see Solubles, condensed)
- Streams
 2: 147 (fish and invertebrates in Ontario)
- Structure, ocean water (see also Oceanography)
 5: 567 (of NE Pacific during August 1955)
- Sturgeon, shortnose (*Acipenser brevirostrum*)
 4: 503 (first Canadian record)
- Sturgeons (*Acipenser* spp.)
 4: 515 (seasonal "races" among European species)

Subarctic waters

- 6: 795 (
- Sagitta*
- in Pacific)

Subrahmanyam, Vaidyanatha Iyer

- 1: 1 (antibiotic for holding freshwater fish products in tropics)

Sucker, common (*Catostomus commersoni*)

- 2: 175 (respiration)

Sulphate

- 1: 7 (in Atlantic coastal sea water)

Sund, Paul Nathan

- 3: 351 (distribution of
- Chaetognatha*
- in Gulf of Alaska)

Survival rate

- 6: 835 (of eggs and fry and in relation to density)

Systematics

- 6: 763 (
- Sebastes m. marinus*
- and
- S. marinus mentella*
-)

- 6: 903 (
- Salmo c. clarki*
- and
- S. c. lewisi*
-)

T

Tagging (see Marking)

Tarr, Hugh Lewis Aubrey

- 6: 791 (keeping quality of dogfish flesh)

Taste (see Quality; Test, freshness)

Temperature (see also Limnology; Oceanography)

- 1: 43 (effect on lipase activity)

- 1: 107 (of
- L. Winnipeg*
- , in relation, to whitefish catches)

- 4: 459 (of Arctic climate and sea water)

- 5: 569 (of NE Pacific Ocean during August 1955)

- 5: 755 (effect on lipase activity)

Templeman, Wilfred

- 6: 763 (caudal pigmentation of redfish larvae)

Terramycin (OTC, oxytetracycline) (see Antibiotic; Quality)

Test, freshness (see also Quality)

- 1: 1 (organoleptic; total volatile base; volatile reducing substances)

- 1: 13, 21 (odour)

- 1: 43 (free fatty acids in frozen fillets)

- 2: 223 (trimethylamine in iced cod)

- 4: 555 (trimethylamine for grading quality)

- 5: 747 (trimethylamine for proteolysis)

- 6: 791 (trimethylamine, total volatile base)

Testes

- 4: 559 (androgen content of sockeye salmon)

Testosterone (see Androgen)

Thermocline (see Limnology; Oceanography; Temperature)

TMA (see Trimethylamine)

Tomlinson, Neil

- 4: 421 (nucleic acids of sockeye salmon during spawning migration)

- 6: 930 (correction)

Total volatile base (see Test, freshness)

Transport, of marine water masses

- 4: 605 (in NE Pacific during August 1955)

- 5: 672 (in Knight Inlet, B.C.)

Trimethylamine (TMA) and oxide

- 1: 13, 21 (in relation to bacterial production of odours)

- 1: 43 (in relation to lipid hydrolysis in flesh)

- 2: 223 (criterion of quality in cod landed seasonally)

- 4: 555 (comparisons of use of for grading quality)

- 5: 747 (relation to proteolysis)

Tropomyosin (see also Actomyosin)

- 1: 53 (isolation from cod muscle)

Trout, brook (*Salvelinus fontinalis*)

- 2: 147 (occurrence and associates in Ontario)

- 2: 175 (respiration)

- 6: 887 (production increased by farmland drainage)

Trout, cutthroat (*Salmo clarki*)

- 6: 903 (differences between subspecies)

Trout, hatchery

- 3: 386 (correction)

Trout, rainbow (*Salmo gairdneri*)

- 3: 247 (movements in Paul L.)

- 3: 321 (diet, glycogen, fatigue)

- 4: 391 (effects of severe exercise)

- 5: 695 (homing in Loon L.)

Trout, steelhead (*Salmo gairdneri*)

- 4: 503 (in Prince Edward Island)

- 5: 721 (growth computation)

Tsuyuki, Hiroshi

- 4: 559 (testicular androgen of sockeye salmon during spawning migration)

- 6: 931 (correction)

Tuna, Pacific blufin (*Thunnus saliens*)

- 3: 383 (off British Columbia)

U

Urea

- 6: 791 (in dogfish flesh)

V

- Vanadium
 1: 7 (undetectable in Atlantic coastal water)
 Vancouver Island, B.C.
 5: 761 (discovery of *Emerita*)
 Vernal and hiemal races
 4: 515 (among anadromous fishes)
 Vertebrae
 6: 903 (number in cutthroat trout)
 Virtual populations
 1: 73 (mortality estimates from)
 Viscosity
 4: 561 (of whale and herring solubles)
 5: 685 (of condensed herring etc. solubles)
 Visweswariah, Krishnamurthy
 1: 1 (antibiotic for holding freshwater fish products in tropics)
 Vitamin B₁₂
 5: 685 (in condensed solubles)

W

- Walford line
 5: 740 (chinook salmon)
 Walleye (*Stizostedion vitreum*)
 1: 131 (L. Winnipeg catches, C/E, and size)
 Water, content in fish
 2: 235 (changes in sockeye salmon during spawning migration)
 5: 679 (seasonal variation, Pacific herring)
 Watson, Nelson Herbert Frank
 6: 929 (correction)
 Weakfish (*Cynoscion regalis*)
 4: 503 (first Canadian record)
 Whale-lice (Cyamidae—Amphipoda)
 3: 385 (correction)
 Whales
 3: 385 (correction)

Whales (technology)

- 4: 561 (viscosity and enzyme treatment of solubles)
 Whitefish (*Coregonus clupeaformis*)
 1: 107, 131 (L. Winnipeg fishery)
 4: 503 (records from Maritime Provinces)
 Wickett, William Percy
 3: 385, 386 (corrections)
 Winchester, Paul Maurice
 1: 33 (chemistry of fish muscle protein)
 Wind effects
 4: 612 (on NE Pacific Ocean during August 1955)
 5: 671 (on ship, etc. during current measurement)
 Winnipeg, Lake
 1: 107, 131 (fisheries)
 1: 144 (winter temperatures, O₂, CO₂)
 Wood, James Douglas
 5: 755 (refrigeration effect on lipase in lingcod filets)

Y

- Young, Elrid Gordon
 1: 7 (composition of Atlantic coastal sea water)
 6: 930 (correction)

Z

- Zeaxanthin (*see* Pigment)
 Zinc
 1: 7 (in Atlantic coastal sea water)
 Zooplankton (*see also* Plankton)
 3: 283 (in Barkley Sound, B.C.)
 3: 351 (*Chaetognatha*)
 4: 453 (in Arctic sea waters near Igloolik, N.W.T.)

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